Vol. II

TRANSCRIPT OF RECORD

Supreme Court of the United States

OCTOBER TERM, 1938

No. 127

MACKAY RADIO AND TELEGRAPH COMPANY, INC.,
PETITIONER,

vs.

RADIO CORPORATION OF AMERICA

ON WRIT OF CERTIORARI TO THE UNITED STATES CIRCUIT COURT
OF APPEALS FOR THE SECOND CIRCUIT

PETITION FOR CERTIORARI FILED JUNE 17, 1938.

CERTIORARI GRANTED OCTOBER 10, 1938.

SUPREME COURT OF THE UNITED STATES

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No. 127

MACKAY RADIO AND TELEGRAPH COMPANY, INC.,
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VOL. II

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JUDD & DETWEILER (INC.), PRINTERS, WASHINGTON, D. C., NOVEMBER 7, 1938.

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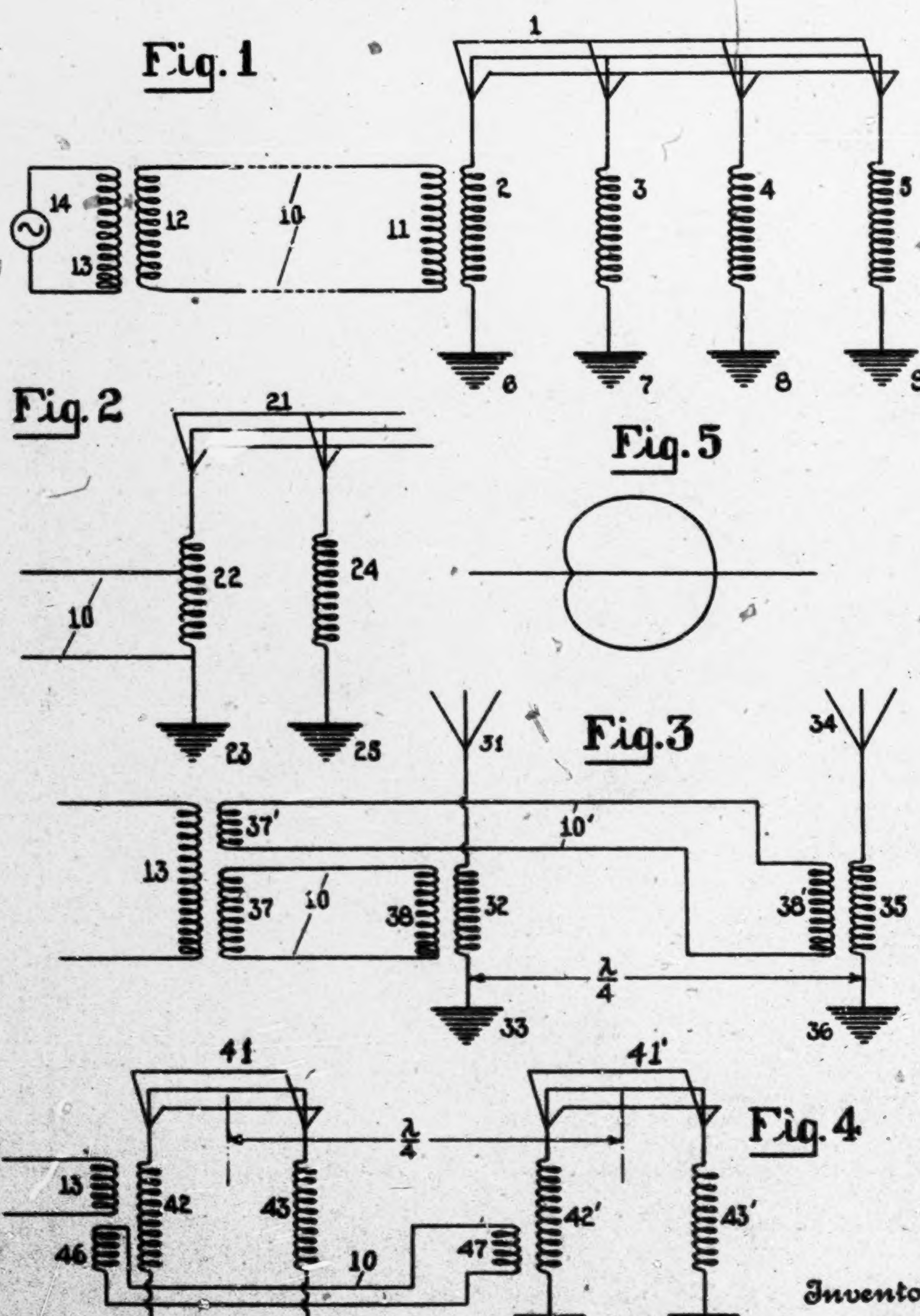
April 12, 1927. 1,623,996

P. S. CARTER

RADIO TRANSMISSION SYSTEM

Original Filed June 25, 1923



Inventor
PHILIP S. CARTER
By his Attorney
Ira J Adams

1,623,996

Patented Apr. 12, 1927.

UNITED STATES PATENT OFFICE.

PHILIP S. CARTER, OF NEW BRUNSWICK, NEW JERSEY, ASSIGNOR TO RADIO CORPORATION OF AMERICA, A CORPORATION OF DELAWARE.

RADIO TRANSMISSION SYSTEM.

Application filed June 25, 1923, Serial No. 647,463. Renewed February 12, 1925.

This invention relates to a new and improved radio signaling system and more specifically to improved means for transferring radio frequency energy, generated at a power house, to the antenna or energy radiating circuit.

In the past it has been the custom to erect the antenna of a transmitting system as close as possible to the point where the radio frequency power is generated in order to have a minimum power loss between the generator and the antenna, in the interests of efficiency and economy. However, circumstances occasionally arise where local geographical conditions or considerations of economy render it desirable to make use of an antenna which is located at a distance from the power house. In the past, under such conditions, it was not possible to work efficiently, particularly with short waves, since a given length of transmission line with such waves represents a greater electrical distance than with long waves.

My invention has for objects the provision of a transmission line which will supply radio frequency energy from a power house to an antenna located at a considerable distance away, thus making possible the utilization of existing apparatus at a high efficiency where hitherto only a low efficiency was possible. Another object of the invention is to provide a new and improved system giving directional transmission utilizing separate antennæ fed from a single source through a plurality of transmission lines.

My invention is illustrated in the accompanying drawing, in which—

Figure 1 represents a multiple tuned antenna connected to a source of power through a transmission line of relatively great electrical length.

Figure 2 shows an equivalent method of coupling the transmission line to the antenna.

Figures 3 and 4 represent different forms of a directional system according to my invention, utilizing a plurality of antennæ supplied from a single source by means of transmission lines.

Figure 5 shows the directional characteristics of the arrangement disclosed in Figures 3 and 4.

My invention, both as to its theoretical principles and its practical application, will best be understood by reference to the specification in connection with the drawing, but its scope will particularly be pointed out in the appended claims.

Referring to Figure 1, 1 designates a long or multiple tuned antenna grounded at points 6, 7, 8 and 9 through inductances 2, 3, 4 and 5. A transmission line 10 is coupled by means of coil 11 to inductance 2 as will be more particularly pointed out later. An inductance 12 connected across said transmission line is coupled to inductance 13 connected across the terminals of a source of power 14. For the purpose of example this is shown in the drawing as an alternator, although any other suitable source, such for instance as an arc converter or a vacuum tube oscillator may be used for supplying power to the transmission line and antenna.

In order to economize in the generating and power transmitting apparatus, it is highly desirable that the apparatus should work at unity-power factor; that is to say, that the current and voltage in the transmission line should be in phase. The power loss (including radiation) in any transmission line is I^2R where I represents current and R the effective A. C. resistance, including radiation resistance. When the transmission is at unity power factor, losses in the line are a minimum. Such a result may be obtained if the transmission line is made reflectionless or of electrically infinite length. Under these conditions no waves can be reflected back from the ends to interfere with the natural flow of energy into and out of the transmission line. This result may be obtained by closing the transmission line 10 at 11 in such a manner that the effective impedance at the load end of the line is equal to the surge impedance of the transmission line.

I have found that in the case of a multiple tuned antenna this condition is obtained when the feed ratio is equal to $\sqrt{\frac{Z_o}{R}}$ where Z_o is equal to the surge impedance of the transmission line $\left(=\sqrt{\frac{L}{C}}\text{ approx}\right)$ and "R" equals the antenna resistance, or stated differently, the antenna resistance multiplied by the square of the feed ratio should be equal to the surge impedance of the line.

Referring to Figure 2, an equivalent

method of connecting the transmission line 10 to a multiple tuned antenna is shown. Here, 21 designates the antenna grounded at 23, 25, etc. through coils 22, 24, etc. The transmission line 10 is closed through a suitable amount of coil 22 such that the effective impedance of this part of coil 22 with its antenna load is equal to the surge impedance of the line.

Referring to Figure 3, I have shown a plurality of open antennæ 31 and 34 provided with inductances 32 and 35 and grounded at 33 and 36. These antennæ are located ¼ wave length apart and are energized by means of transmission lines 10 and 10′ which are coupled through coupling coils 37, 37′ and 13 to a generator (not shown) and through coils 38 and 38′ to coils 32 and 35. Obviously, the same adjustment of coupling coils 38 and 38′ is made as before.

Figure 4 shows an arrangement substantially equivalent to that shown in Figure 3 with the exception that two multiple tuned antennæ are used instead of the two open antennæ. In this figure 41 and 41′ represent two multiple tuned antennæ grounded at 44, 45 and 44′, 45′, respectively through inductances 42, 43 and 42′, 43′. A generator (not shown) is arranged to feed antenna 41 and energy is supplied to antenna 41′ by means of the transmission line 10 coupled to the source by means of coils 13 and 46 and to antenna coil 42′ by coil 47. The coupling between the transmission line and the antenna should be adjusted to give an effective impedance equal to the surge impedance of the line. It will be seen that this arrangement is somewhat directional as shown in Fig. 5.

It is to be noted that my transmission line lends itself particularly to directional systems comprising a plurality of antennæ, since the proper phase relation of currents in the various antennæ can readily be obtained with a maximum efficiency of transmission line.

While I have shown and described the preferred form of my invention I wish it understood that I do not limit myself to the arrangements shown and described, but that modifications and changes may be made within the scope of my invention as will be evident to those skilled in the art to which it appertains.

Having described my invention, what I claim is:

1. In a radio signalling system, the combination of an energy radiating circuit, a source of power for energizing said circuit and a transmission line of electrically infinite length connecting said circuit and said source.

2. In a radio signalling system, the combination of an energy radiating circuit, a source for supplying energy to said circuit and a transmission line connecting said source and said circuit, said transmission line being constructed and arranged so as to be substantially reflectionless.

3. In a radio signalling system, the combination of an antenna constructed and arranged to radiate energy, a source for supplying energy to said antenna and a conducting line connecting said source and said antenna, said line being so constructed and arranged as to prevent the formation of standing waves thereon.

4. In a radio signalling system, the combination of an antenna arranged to radiate energy, a source for supplying said antenna with energy to be radiated and means for transferring energy from said source to said antenna, said means being so constructed and arranged that the voltage and current components of the energy travelling thereon are always in phase.

5. In a radio signalling system, the combination of an antenna arranged to radiate energy, a source for supplying energy thereto and a transmission line connecting said source and said antenna, the effective impedance at the antenna end of said transmission line being equal to the surge impedance of the line.

6. In a radio signalling system, the combination of a multiple tuned antenna, a source of power for said antenna and a transmission line for connecting said antenna and said source, characterized by the fact that the antenna resistance multiplied by the feed ratio squared is substantially equal to the surge impedance of the line.

7. In a radio signalling system, the combination of a plurality of antennæ, a single source for supplying energy to all of said antennæ and transmission lines of electrically infinite length for supplying energy from said source to said antennæ.

8. In combination, antennæ having a single source of power supply and grounded through inductances, the source of supply energizing that part of the inductance necessary to give an effective load resistance equal to the surge resistance of transmission means connecting the source and the antennæ.

PHILIP S. CARTER.

[fols. 651-654] PLAINTIFF'S EXHIBIT No. 2

465

May 16, 1933. P. S. CARTER 1,909,610

ELECTRIC CIRCUIT

Filed March 12, 1930

Fig. 1

Fig. 2

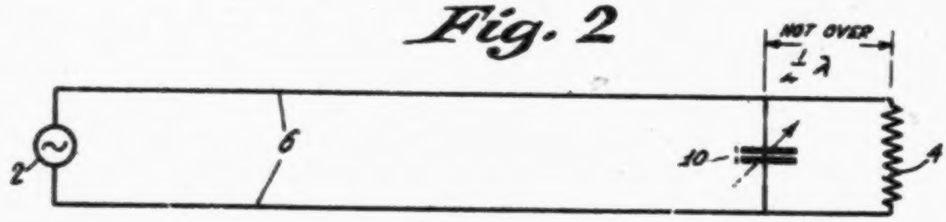


Fig. 3

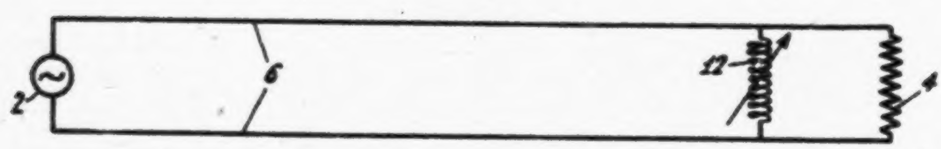


Fig. 4

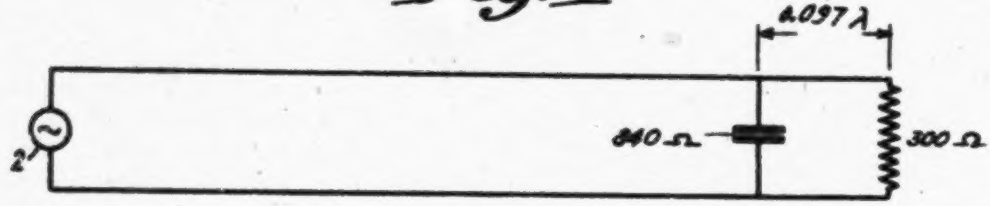
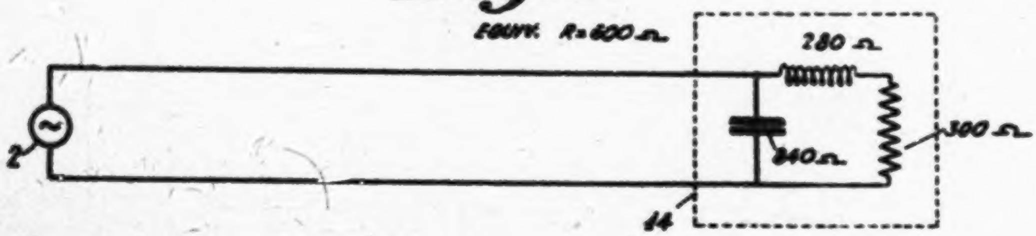


Fig. 5



INVENTOR
PHILIP S. CARTER
BY H. G. Grover
ATTORNEY

Patented May 16, 1933

1,909,610

UNITED STATES PATENT OFFICE

PHILIP STAATS CARTER, OF PORT JEFFERSON, NEW YORK, ASSIGNOR TO RADIO CORPORATION OF AMERICA, A CORPORATION OF DELAWARE

ELECTRIC CIRCUIT

Application filed March 12, 1930. Serial No. 435,281.

This invention relates to electric circuits and especially to a transmission line supplying high frequency currents to a high frequency load circuit. In order that the line transmit energy at best efficiency; that is to say, without reflection, it is desirable that the line be terminated by a load which equals in impedance the surge impedance of the line. As lines and loads are independently designed; or, as it often occurs that existing lines must be connected with existing loads which do not have the requisite values of impedance for best energy transmission over the lines, it is an object of my invention to provide a method and means for terminating a line to which a load is connected so that the termination means combined with the load presents the correct impedance to the line. More specifically, I accomplish this by connecting a variable reactance across the line at a distance away from the load such that the circuit formed thereby including the variable reactance, the line portion between it and the load, and the load, presents an impedance equivalent to the surge impedance of the line.

In a case wherein the surge impedance is greater than the load impedance or resistance, I have discovered that by connecting a capacitive reactance across the line at a distance not more than one-quarter of a wave length of the energy transmitted by the line away from the load; or, by connecting an inductive reactance across the line at a distance more than one-quarter wave length but less than one-half wave length of the load, the combination of the reactance, load and portion of the line included between the reactance and the load becomes equivalent, with proper quantitative values of the electrical elements involved to the surge impedance of the line, therby facilitating efficient energy transmission.

Similarly I have discovered that when the surge impedance of the line is less than the load impedance, by connecting an inductive reactance across the line not more than one-quarter wave length away from it; or, a capacitive reactance across the line more than one-quarter wave length but less than one-half wave length away from the load, that the combination of reactance, load and portion of the line included between the reactance and the load becomes equivalent, with proper quantitative values of the electrical elements involved to the surge impedance of the line thereby properly terminating it for maximum energy transmission. Similar results can, of course, be obtained if multiples of the distances given are chosen. Thus, for example, where the surge impedance is greater than the load resistance, a capacity reactance may be connected across the line at a distance away from the load not over three-quarters and more than one-half wave length away from the load and the reactance plus the portion of the line included between it and the load together with the load will provide for the line an impedance equivalent to its surge impedance.

Although I have defined my invention in particularity in the appended claims, it may best be understood by referring to the accompanying drawing in which

Figure 1 generically discloses my invention for properly terminating the line so that the load plus the terminating circuit equals the surge impedance of the line,

Figure 2 illustrates a terminating arrangement wherein the load resistance is less than the surge impedance; or, in other words where the surge impedance is greater than the load impedance,

Figure 3 illustrates an arrangement for properly terminating a line wherein the load resistance is greater than the surge impedance of the line,

Figure 4 illustrates the actual constants used to properly terminate a line of 600 ohms surge impedance when the load thereacross is 300 ohms, and

Figure 5 illustrates the equivalent lumped electrical circuit of Figure 4.

Turning to Figure 1, a source of alternating energy 2 feeds energy to a load impedance 4 through the intermediary of the transmission line 6. In order that energy may be conveyed at maximum efficiency

along the line 6, the surge impedance of line 6 should be equal in value to the impedance of load 4. In practice, as already indicated, it rarely occurs that the load has the correct impedance value so as to match the surge impedance of the line to which it is connected. In order to properly match the load and line, according to my invention, I connect across the line at suitable distance away from the load a variable reactance 8 of such a value and at such a distance away from the load 4 that the reactance 8, the load 4 and the portion 6′ of the line 6 included therebetween, equals in value the surge impedance of the line, thereby allowing of most efficient energy transfer from source 2 along the line 6.

In the case where the surge impedance is greater than the load impedance or load resistance, by connecting a capacitive reactance 10 such as shown in Figure 2 across the transmission line 6 at a distance away from the load not more than one-quarter wave length of the energy derived from source 2 and transmitted along line 6, the combination of the capacitive reactance 10 and the portion of the line 6 between it and the load resistance 4 will so terminate the line that it faces an impedance equivalent to its surge impedance. The same result is obtained by connecting an inductive reactance across the line at a distance away from the load 4 not over one-half wave length and not less than one-quarter wave length. Again, the same result, where the surge impedance of the line is greater than the load resistance, is obtained by connecting a capacitive reactance across the line at a distance away from the load between three-quarter and one-half wave length; etc. I prefer, however, to use as small a section of the line as possible in order to properly terminate it.

In the event that the surge impedance is less than the load resistance, proper line termination is obtained by connecting an inductive reactance 12, as shown in Figure 3, at a distance away from the load resistance not over one-quarter wave length of the energy transmitted by the two wire transmission line 6. The same result is obtained by connecting in Figure 3, in place of inductance 12 a variable capacitive reactance (it is to be understood, of course, that all of the reactances so far mentioned may be variable as indicated on the drawing) between one-half wave length and one-quarter wave length away from the load 4. Similarly, the same result can be obtained by connecting an inductive reactance across the line between three-quarter and one-half wave length away from the load resistance 4; etc. However, as I have stated with reference to the invention as disclosed in Figure 2, I prefer to connect a suitable reactance across the line as closely as possible to the load so as to include a minimum section of the line between the reactance and the load.

In Figure 4, I have shown the actual values of the elements involved where a line having a surge impedance of 600 ohms supplies a load of 300 ohms. In order to properly terminate a line a capacitive reactance of 840 ohms with respect to the frequency of the radio frequency energy being conducted parallels the load at a distance of 0.097 of the wave length employed.

In Figure 5 the equivalent electrical circuit 14 is disclosed and it is shown that the portion of the line included between the capacitive reactance and the load is equivalent to a lumped inductive reactance of 280 ohms.

In order to fix more clearly in mind the line sections and reactances to be used for properly terminating a line so that it faces an impedance equivalent to its surge impedance, the following table, which is self explanatory, wherein Z_0 indicates the surge impedance of the line, is given.

Load resistance.	Line section length.	Reactance necessary to match line.
Less than Z_0	Less than ¼ W. L.	Capacity.
Greater than Z_0	Less than ¼ W. L.	Inductance.
Less than Z_0	Greater than ¼ but less than ½ W. L.	Inductance.
Greater than Z_0	Greater than ¼ but less than ½ W. L.	Capacity.

What I claim is:

1. In combination, a source of energy, a load, a transmission line extending between said source of energy and said load, means for matching said load to the surge impedance of said line consisting of a reactance connected across said line between said load and said source and so arranged that a portion of said line is located between said reactance and load, said reactance having such value that the combination only of the load, portion of the line, and the reactance becomes equivalent to the surge impedance of said transmission line.

2. A combination as defined in claim 1 characterized in this, that said reactance comprises a variable element, and said transmission line comprises an unbroken, linear connection characterized by the absence of serially connected impedances between said source and said load.

3. In combination, a source of energy, a load having a predetermined resistance, a transmission line extending between said source of energy and said load and having a surge impedance greater than the load resistance, a capacitive reactance connected across said line between said load and said source and so arranged that a portion of said line not exceeding a quarter wave length is located between said reactance and said load

for matching said load to the surge impedance of said line, said capacitive reactance having such value that the combination only of the load, portion of the line, and the reactance becomes equivalent to the impedance of said transmission line.

4. In combination, a source of energy, a load having a predetermined resistance, a transmission line extending between said source of energy and said load and having a surge impedance greater than the load resistance, an inductive reactance connected across said line between said load and said source and so arranged that a portion of said line between one quarter and one half wave length is located between said reactance and load, said inductive reactance having such value that the combination only of the load, portion of the line, and the reactance becomes equivalent to the surge impedance of said transmission line.

5. In combination, a source of energy, a load having a predetermined resistance, a transmission line extending between said source of energy and said load and having a surge impedance less than the load resistance, an inductive reactance connected across said line between said load and said source and so arranged that a portion of said line less than one quarter wave length is located between said reactance and said load for matching said load resistance to the surge impedance of said line, said inductive reactance having such value that the combination only of the load, portion of the line, and the reactance becomes equivalent to the surge impedance of said transmission line.

PHILIP STAATS CARTER.

[fols. 655-670] PLAINTIFF'S EXHIBIT No. 3

Oct. 25, 1932. N. E. LINDENBLAD 1,884,006

ANTENNA

Filed Sept. 7, 1928 4 Sheets-Sheet 1

Fig. 1

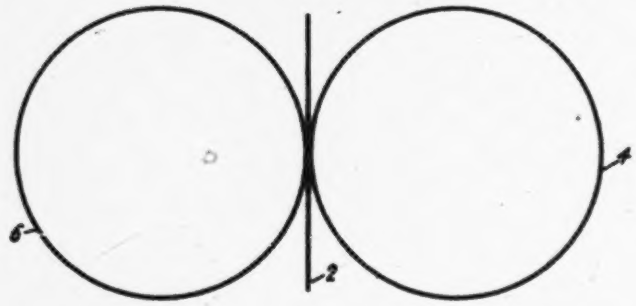


Fig. 2

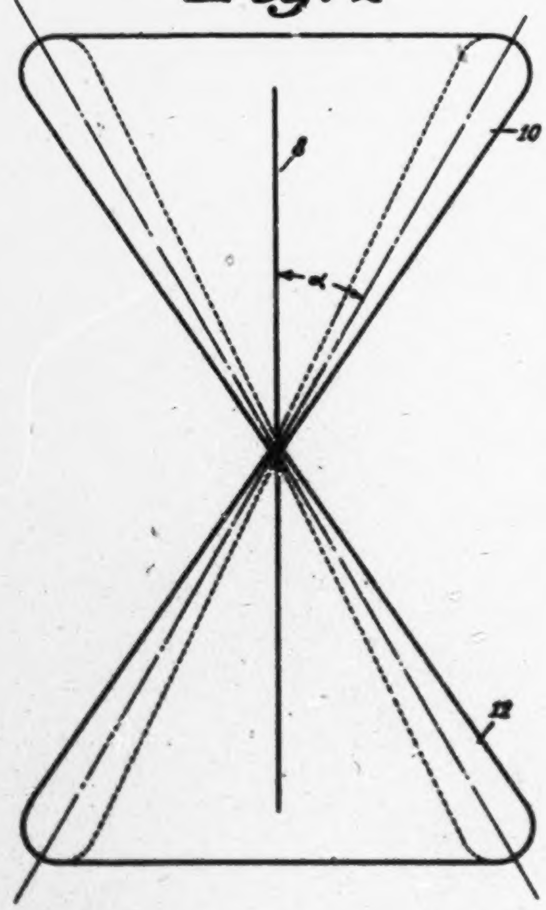
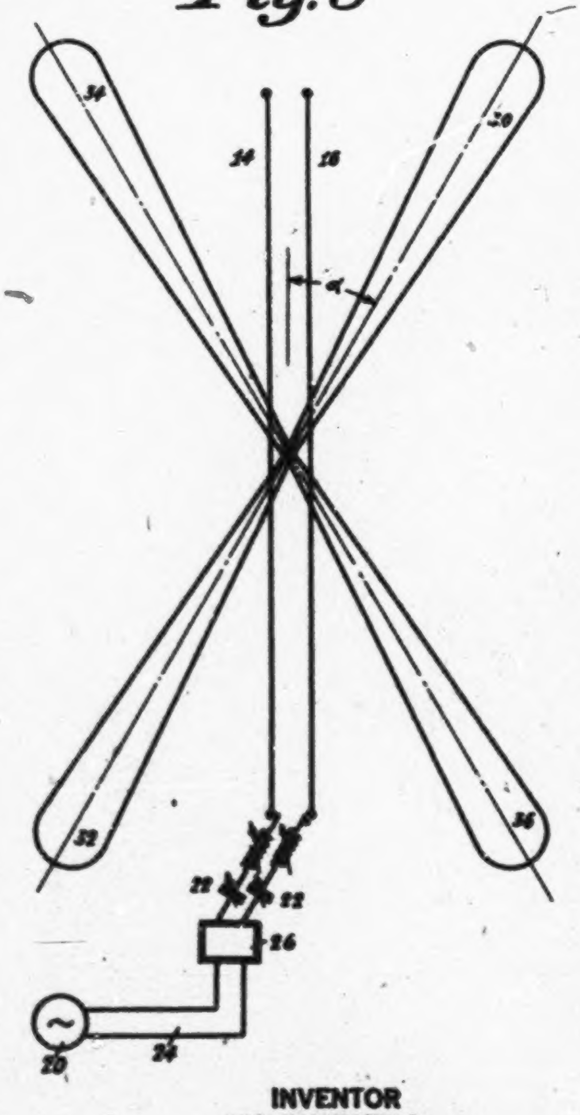


Fig. 3



INVENTOR
NILS E. LINDENBLAD
BY Ira J. Adams
ATTORNEY

Oct. 25, 1932. N. E. LINDENBLAD 1,884,006

ANTENNA

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Fig. 4

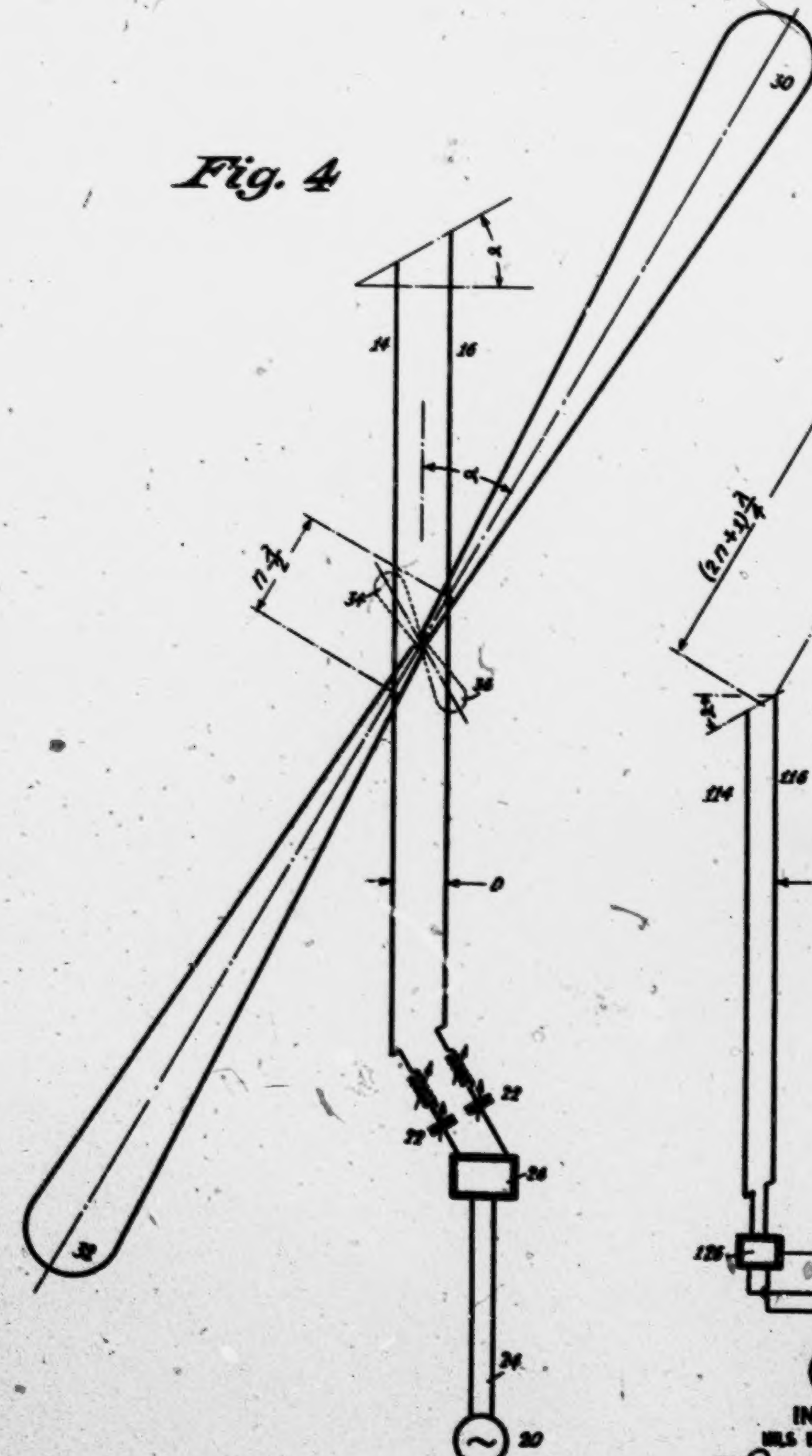
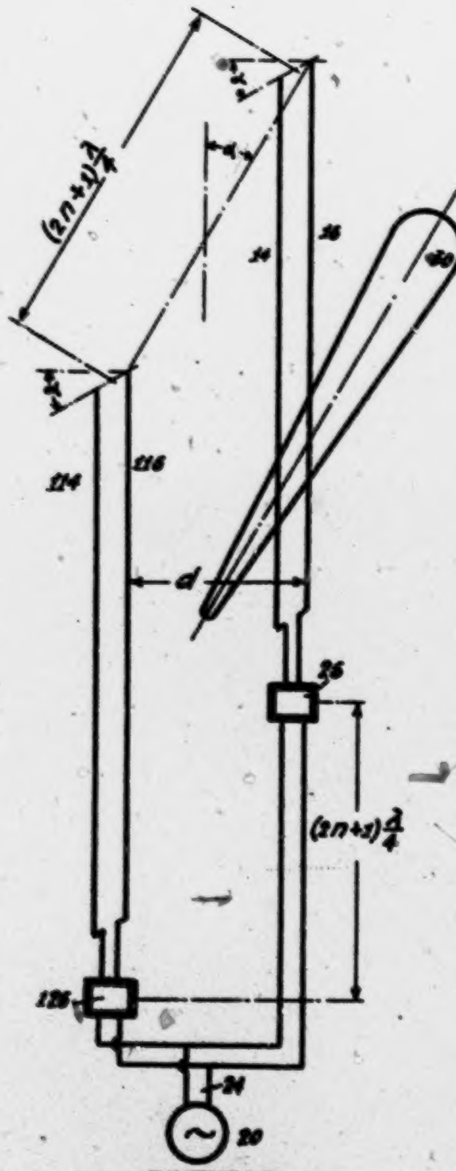


Fig. 5



INVENTOR
NILS E. LINDENBLAD
BY Ira J. Adams
ATTORNEY

Oct. 25, 1932. N. E. LINDENBLAD 1,884,006

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Fig. 6

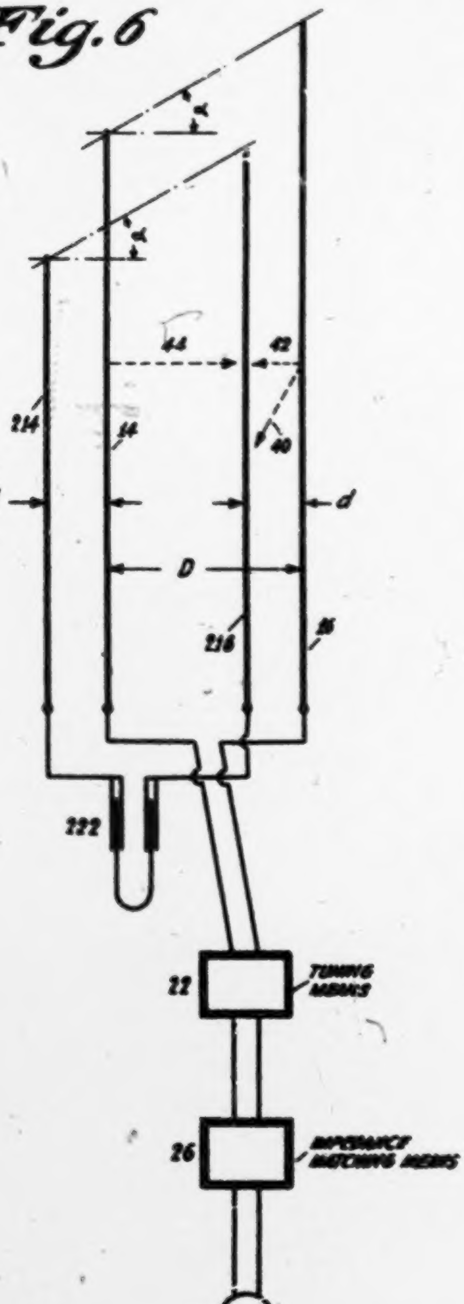
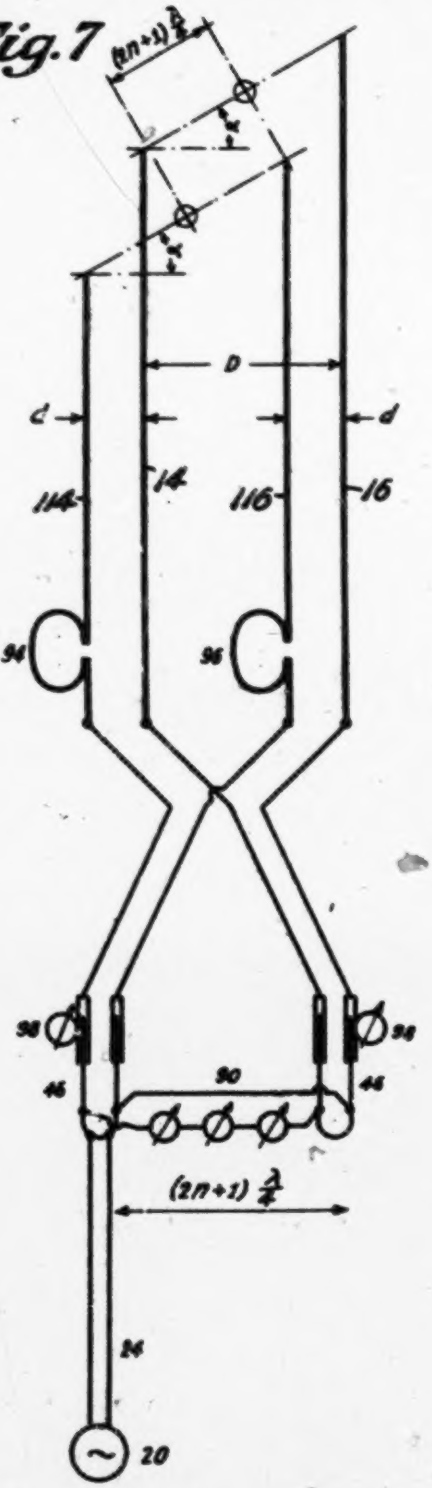


Fig. 7



INVENTOR
NILS E. LINDENBLAD
BY Ira J. Adams
ATTORNEY

Oct. 25, 1932. N. E. LINDENBLAD 1,884,006

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Filed Sept. 7, 1928 4 Sheets-Sheet 4

Fig. 8

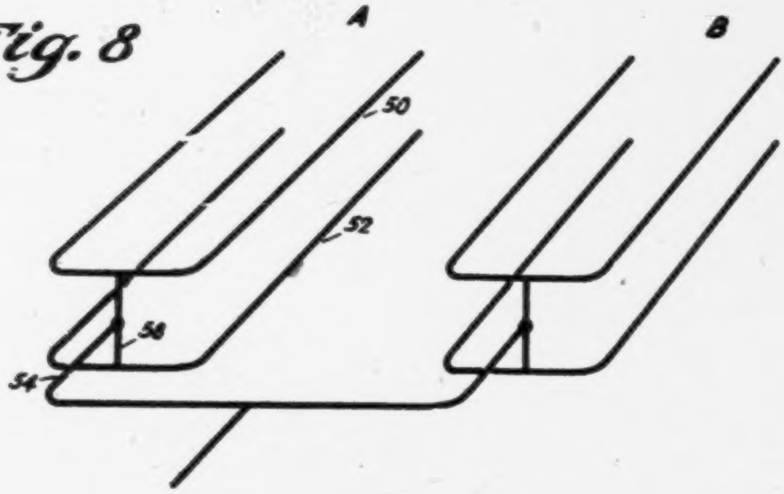


Fig. 9

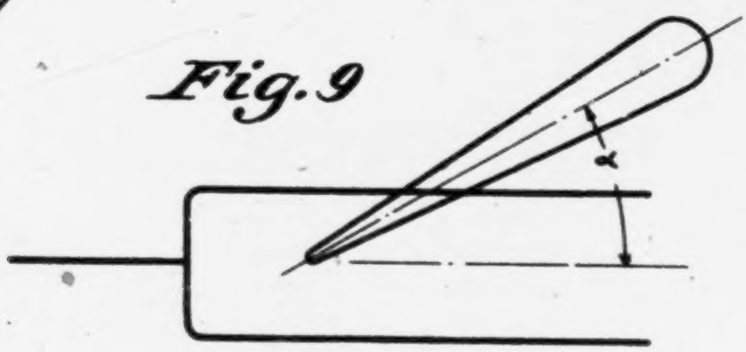
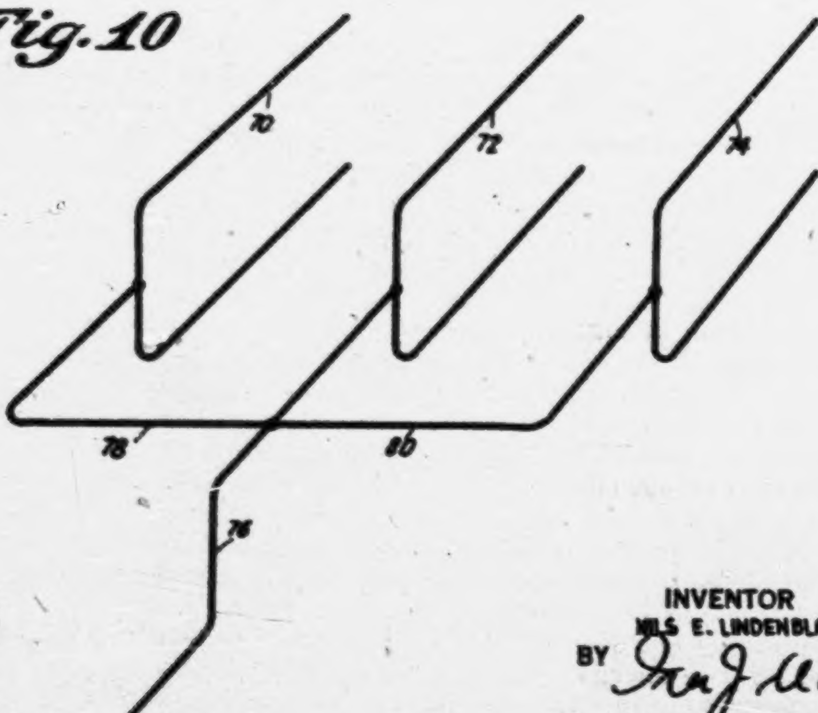


Fig. 10



INVENTOR
NILS E. LINDENBLAD
BY Ira J. Adams
ATTORNEY

Patented Oct. 25, 1932 1,884,006

UNITED STATES PATENT OFFICE

NILS E. LINDENBLAD, OF ROCKY POINT, NEW YORK, ASSIGNOR TO RADIO CORPORATION OF AMERICA, A CORPORATION OF DELAWARE

ANTENNA

Application filed September 7, 1928. Serial No. 304,443.

This invention relates to antennæ, and more particularly to directional antennæ for the propagation or reception of short wave signals.

Several types of beam and projector antenna systems for short waves have been developed, but these are rather complicated in structure and therefore relatively expensive to erect and adjust, and also are structurally suitable only for the wave length for which they have been designed and built. It is the primary object of my invention to provide a simplified antenna which will be capable of accommodating a broad range of wave lengths, and to this end I have experimented very extensively with the problem of radiation from transmission lines, as a result of which I have devised an antenna consisting merely of simple linear conductors. The antenna is suitable both for transmission and reception, but for simplification I shall refer to transmission in the description which follows. Identical structure and theory may be applied to reception.

If a standing wave is caused on a linear conductor which is long, relative to the working wave length, the conductor may be considered as composed of successive half wave length linear oscillators connected end to end, in which case there will be no summation of energy nor radiation in an end-on direction because each of the half wave oscillators does not radiate along its axis. Furthermore, there is no radiation at right angles to the wire because although each half wave length oscillator might tend to radiate in this direction, the successive half wave length radiators are opposed in phase, so that at a distance from the wire the average effect is zero. However, there is radiation in a direction intermediate the normal and longitudinal directions, and with a single conductor, this radiation takes place in the form of hollow cones having common axes in the wire.

This is wasteful of energy, and one object of my invention is to reduce the conical radiation so that it will consist only of concentrated lobes having axes in one plane. This is accomplished by providing two collaterally spaced substantially parallel linear conductors which are long, relative to the working wave length, and which are coupled in phase opposition. Because of the opposed phase relation in the two conductors there is substantially no radiation normal to the plane of the conductors, that is, by spacing them apart the radiation from the pair of conductors is concentrated, essentially, into conjugate pairs of oppositely directed lobes the axes of which lie in the plane of the conductors.

This arrangement, too, is wasteful of energy, and it is a further object of my invention to strengthen the radiation in one pair of opposite critical directions, while weakening the radiation in the conjugate pair of opposite critical directions, which I do by staggering the pair of wires, longitudinally, so that their ends make an angle with the transverse axis of the antenna equal to the critical angle of radiation, that is, the angle which the principal lobes of the radiation pattern of the antenna make with the longitudinal axis of the antenna. In this manner radiation in one pair of opposite directions from each of the conductors come on the same wave front at the same time, but being opposite in phase, they neutralize and cancel each other. In the conjugate directions, owing to the physical displacement of the conductors, the radiated energy tends to add. To make this addition a maximum it is desirable that the added energies be combined exactly in phase, and to provide for this the spacing of the pair of wires should be such that their distance apart, measured in the direction of radiation, is an odd number of half wave lengths.

The radiation has so far been reduced to a bidirectional radiation, and a further object of my invention is to make it unidirective, for which purpose I provide another pair of simple linear conductors arranged to form another antenna such as I have already described, spaced apart from the first antenna an odd number of quarter wave lengths in the direction of desired propagation, and energized in phase quadrature so that the entire system is made unidirective.

Instead of forced feeding of energy to the

second antenna a pure reflector action may be employed, in which case only one of the pairs of conductors is energized, in the case of a transmitter, or connected to the receiving set, in the case of a receiver, while the other pair of conductors is properly tuned and spaced and staggered so as to provide reflector action by reason of the energy transferred thereto from the other pair of conductors.

It has already been mentioned that the use of a pair of conductors causes the radiation to lie more nearly in a single plane, and in order to improve this characteristic a number of stories of antennæ, such as I have already described, may be employed, each antenna consisting of conductors lying in a single plane, while the various antennæ lie in vertically spaced parallel planes, and are coupled together so as to operate electrically in parallel. The spacing of these planes may be any spacing desired, particularly if a large number is used, but should preferably be a half wave length, especially when only two antennæ are used.

To sharpen the directivity in azimuth a number of antennæ may be used which are spaced apart in a horizontal direction, so as to present a broadside array.

A further object of my invention is to elevate the propagated wave, and this may be done either by arranging the antenna system with the linear conductors spaced apart in a horizontal direction, but with their plane tilted upwards in the direction of desired propagation, or by arranging all of the conductors so that they lie in a vertical plane, and are spaced apart vertically, and either lie horizontally in said plane, or at such an angle with the horizontal that the wave is propagated at the desired elevation. To then sharpen the directivity in azimuth a number of such antennæ lying in horizontally spaced vertical planes may be used.

The invention is described more in detail in the following specification, which is accompanied by drawings in which

Figures 1 and 2 are explanatory of my invention;

Figure 3 represents my antenna in simplest form;

Figure 4 represents a bidirective antenna constructed in accordance with my invention;

Figure 5 is a unidirective antenna employing an energized reflector;

Figure 6 is a unidirective antenna employing a tuned reflector;

Figure 7 is a modification of Fig. 5;

Figure 8 indicates schematically an antenna system employing a plurality of antennæ spaced vertically and horizontally to increase directivity in elevation and in azimuth, respectively;

Figure 9 is a schematic representation of an antenna and reflector lying in a vertical plane to obtain elevated radiation; and

Figure 10 indicates schematically a broadside aray of antennæ lying in vertical planes to increase the directivity in azimuth.

In Figure 1 there is shown a simple linear conductor 2 a half wave in length. The maximum radiation from this conductor takes place normally of the conductor, the pattern, in section, being a figure 8 such as is indicated by the lobes 4 and 6.

When a conductor which is long, relative to the wave length, is employed, and a standing wave is caused thereon, the radiation normal of the conductor is opposed in phase in the successive half wave length portions of the conductor, and consequently there is no radiation normally of the wire. There is no radiation endwise of the wire because although in this direction radiated energy would add favorably, there is no radiated energy to be added. The radiation takes place in an intermediate direction, and the principal rediation is indicated in Figure 2, in which there is a long conductor 8, on which a standing wave is caused, and from this conductor radiation takes place in conical lobes, such as the lobes 10 and 12. It will be seen from the figure that these lobes are in the form of hollow cones having their apices adjacent and located in the conductor. In actual practice it should be kept in mind that there will be a number of different cones of various lesser magnitudes, and lying in different directions, relative to the longitudinal axis of the antenna, but for the sake of simplicity only the principal radiation is indicated, and its direction is indicated by the angle α.

Referring to Figure 3 it will be seen that there are a pair of long conductors 14 and 16, and that these are substantially parallel and collaterally spaced. The conductors are connected in phase opposition to the transmitter 20 through tuning reactances 22, the latter being adjusted to cause standing waves on the conductors 14 and 16 by making the total electrical length of the circuit around the two wires a whole number of half wave lengths. This number should be odd, in order that the open ends of the conductors may be opposite in polarity. It should be noticed that these wires preferably are left with open ends, as a simple expedient to favor the growth of standing waves. If the transmission line 24 which interconnects the transmitter and the antenna is long, so that standing waves thereon might tend to cause undesired radiation, the transmission line may be closed with an impedance matching device 26, so that standing waves exist only between the device 26 and the antenna, and not on the line 24.

In a direction normal to the plane of the conductors 14 and 16 radiation is cancelled because of the phase opposition of the energy

in the conductors, and consequently the hollow cones of radiation indicated in Figure 2 are reduced to four ears or lobes, the axes of which lie in the plane of the conductors. These lobes may be grouped into the oppositely directed lobes 30 and 32, and a conjugate pair of oppositely directed lobes 34 and 36. The direction of radiation here also makes an angle α with the longitudinal axis of the antenna.

Referring to Figure 4 it will be seen that the arrangement there disclosed is quite similar to that shown in Figure 3 except that the conductors 14 and 16 have been staggered, longitudinally, so that their ends make an angle α with the transverse axis of the antenna. This causes the radiation corresponding to the lobes 34 and 36 in Figure 3 to come on the same wave front at the same time, and being opposed in phase, the radiation is practically cancelled, making the antenna bidirective, in the direction of the lobes 30 and 32, which are correspondingly strengthened, for radiation in this direction is additive, owing to the displacement of the conductors. The transverse spacing of the conductors is indicated by the dimension D, and should be such, preferably, that when multiplied by the cosecant of the angle of radiation α, the product will equal an odd number of half wave lengths, for in this case the radiation from the two conductors will combine exactly in phase.

It is slightly desirable, but not essential, that the spacing D be one or more whole wave lengths, in which case radiation transversely of the antenna will be effectually prevented, but this condition can only be met for certain special cases of the angle α, and is not important, owing to the fact that each wire is essentially non-radiative in a normal direction.

Referring now to Figure 5 it will be seen that there are two pairs of collaterally spaced conductors, 14, 16 and 114, 116, and each of these pairs is arranged in accordance with the principles set forth in connection with Figure 4. The pairs of antennæ are energized in parallel through a branched transmission line system, and the feed is made such that the antennæ are energized in phase quadrature. This may be obtained most simply by having the arms of the branched transmission line differ in length by an odd number of quarter wave lengths, as has been indicated in the drawings, this difference in length being introduced ahead of the impedance matching devices, so that it exists in lines on which there is a travelling wave, rather than a standing wave. The pairs of conductors are spaced apart a distance d, and this distance is such that when multiplied by the cosecant of the angle of principal radiation α, the product will be an odd number of quarter wave lengths, so that owing to the initial phase difference in the energization of the antennæ, the radiated energy in one of the opposite directions, as 30, adds, while in the opposite direction the energies are opposed, and cancel, thereby making the antenna unidirective, instead of bidirective.

The arrangement shown in Figure 5 employs an energized or forced feed reflector, which may be called a director, but it is also possible to use a simple tuned reflector energized from the other pair of conductors. In this case it is desirable to have the reflector near the energized conductors, and in such case the arrangement preferably is slightly modified as in Figure 6, in which the pair of conductors 14 and 16 corresponds to the similarly numbered pair in the preceding figures, while the appropriate reflector wires are numbered 214 and 216. As before, the ends of the conductors 14 and 16 are staggered so as to make an angle α with the transverse axis of the antenna, and the same applies to the reflecting conductors 214 and 216. Also, as before, the distance D is so chosen that when multiplied by the cosecant of the angle α the product will equal an odd number of half wave lengths, so that radiation in the direction of stagger will be added as nearly as possible in phase, and furthermore, the distance D may, if desired, be made one or more whole wave lengths. The conductors 14 and 16 are energized in phase opposition from a transmitter 20, and if desired, an impedance matching device 26, and tuning means 22, may be employed. The conductors 214 and 216 are coupled in phase opposition, and are provided with a tuning means 222, here illustrated as a trombone slide, so that the reflector may be tuned to favor the production of standing waves.

The problem of the spacing and of the stagger of the reflector conductors, relative to the conductors 14 and 16, is not so simple as in the preceding case. If energy were induced in the conductor 216, from the conductor 16, only along the line of direction of principal radiation, as indicated by the dotted arrow 40, the rule would be to make this distance a quarter wave, so that the reflected energy would combine in phase with the energy radiated from the conductor 16 in one direction, and out of phase in the opposite direction. The situation is complicated by the fact that energy is induced in the conductor 216 from the conductor 16 along the shorter normal path, indicated by the arrow 42, and from the conductor 14, indicated by the arrow 44, so that the phase and magnitude of the current in the reflector is the resultant of several factors. The best arrangement may be found by experiment, and stated in a general fashion, the rule is that the spacing and stagger should be such that the effective electrical spacing is a quarter wave, while the reflected energy

comes on the original wave front a quarter wave later.

In Figure 7 there is an energized director 114, 116, as in Fig. 5, but the spacing d between the antenna and the director antenna is made less than the spacing D between the conductors of the antennæ as in Fig. 6. Another feature of this modification is the use of the trombone slides 46 and 48 to tune the antennæ. This tuning need not be great in range, though the antenna structure will cover a great wave length range, because the adjustment can be made for a different number of half waves in length, whenever necessary to accommodate a desired wave length. The transmitter 20 is coupled to the antennæ through a transmission line 24, which is coupled to the trombone slide 46 at points so spaced that the impedance of the line is matched. The trombones 46 are interconnected by a line 90, the ends of which are coupled to the trombone slides at points so spaced that the impedance of the line is matched, so that there is a travelling rather than a standing wave on the line. In this manner the line may be used to introduce a phase change, and is made one, three or five etc., quarter waves in length to obtain phase quadrature in the antennæ. Three meters, 92, are inserted along a quarter wave portion of the line, and are made to read alike when the line is properly adjusted.

The conductors 114 and 116 are lengthened by the addition of the loops 94 and 96, so as to equal the conductors 14 and 16 in length. With this precaution the antennæ should both take equal current. Ammeters 98, shunted to the trombone slides 46, are made to read alike, and at a maximum, when the antenna is properly adjusted.

In connection with Figure 3, and the succeeding figures, it has been pointed out that the radiation takes place principally in the plane of the conductors, and in order to sharpen this characteristic antennæ, such as have already been described, may be located above one another in parallel planes, so as to make a multiple storied antenna. This has been indicated in A, of Figure 8, in which an entire antenna, consisting of a pair of conductors, and either an energized or non-energized pair of reflecting conductors, properly staggered, and lying in a single plane, is schematically indicated by the U shaped line 50. Another such antenna system, lying in a parallel plane, is indicated at 52, and these are fed electrically in parallel through a branched transmission line system, schematically indicated by the single lines 54, 56 and 58. The spacing should preferably be a half or odd number of half wave lengths, so as to provide complete cancellation in an up and down direction. With this type of antenna the structure is arranged at an angle α, in azimuth, relative to the direction in which radiation is desired. If it is desired to sharpen the directivity in this direction, i. e. in azimuth, a plurality of antennæ may be arranged in broadside, and fed cophasially, as is indicated by the antenna systems A and B in Fig. 8. If elevated radiation is desired, the planes in which each antenna lies must be correspondingly tilted or elevated away from a truly horizontal direction. The antennæ so far described provide horizontal polarization.

By positioning the plane of an antenna consisting of two pairs of conductors, such as has already been described in connection with Figures 5, 6, and 7, in a vertical plane, as is indicated in Figure 9, radiation with vertical polarization may be provided. In this case the antenna is directed in the direction of desired propagation in azimuth, and the angle α provides the angle of elevation. This arrangement is desirable because the elevated radiation is obtained without the expense of an elaborate supporting structure for holding the antenna at the corresponding angle. Slight changes in the angle of elevation may be made by slightly changing the position of the conductors, relative to the horizontal, while keeping them in a vertical plane.

In order to sharpen the directivity in azimuth a number of antennæ, located in parallel planes, may be provided as has been indicated in Figure 10, in which each of the antennæ 70, 72, and 74 is an antenna such as has been described in either of Figures 5, 6, or 7, and the various antennæ are energized electrically in parallel through a branched transmission line system 76, 78, 80. The branches are so arranged that the antennæ are energized cophasially, and they are preferably spaced a half wave apart, but may be at any spacing, especially when a considerable number antennæ are employed. This antenna system propagates a vertically polarized elevated wave.

Over a considerable range of tuning the angle α remains quite constant. Only by changing the wave length so greatly that the character of the long wire is completely changed so as to be a relatively few instead of many waves in length, does that lobe of radiation which is greatest in magnitude shift or jump from one to another, so as to definitely and considerably change the angle of radiation α. For example, using conductors approximately eight mean waves in length I have varied the tuning from about five to seven meters without appreciably changing the angle of radiation. The antenna is tuned, but the antenna structure itself need not be changed. The tuning is small in amount because it is needed only to bring the total electrical length to the nearest odd number of half waves, rather than to a fixed length.

I claim:

1. A directional antenna comprising a collaterally spaced pair of simple linear conductors adapted to have standing waves formed thereon which are long, relative to the working wave length, and means energizing said conductors in phase opposition at adjacent ends of said conductors, said conductors lying on the same side as said energizing means and extending away from said energizing means whereby radiant action occurs predominantly in a direction making equal angles greater than zero degrees with reference to said conductors.

2. A directional antenna comprising a collaterally spaced pair of substantially parallel simple linear conductors adapted to have standing waves formed thereon which are long, relative to the working wave length, and means energizing said conductors in phase opposition, said conductors lying on one side of and extending away from said energizing means, radiant action occurring predominantly in a direction making equal angles greater than zero degrees with reference to said conductors.

3. A directional antenna comprising a collaterally spaced pair of substantially parallel simple linear conductors which are long, relative to the working wave length, means coupling said conductors in phase opposition, and means for tuning said conductors and coupling means to an overall electrical length of an odd number of half waves, so as to cause standing waves of opposite polarity on the conductors.

4. A directional antenna comprising a collaterally spaced pair of simple linear conductors which are long, relative to the working wave length, and which are so staggered, longitudinally, that radiation in one pair of opposite critical directions is strengthened, while radiation in the conjugate pair of opposite critical directions is weakened, and means coupling said wires in phase opposition.

5. A directional antenna comprising a collaterally spaced pair of substantially parallel simple linear conductors which are long, relative to the working wave length, and which are so staggered, longitudinally, that radiation in one pair of opposite critical directions is strengthened, while radiation in the conjugate pair of opposite critical directions is weakened, means coupling said conductors in phase opposition, and means for tuning said conductors and coupling means to an overall electrical length of an odd number of half waves, so as to cause standing waves of opposite polarity on the conductors.

6. A directional antenna comprising two pairs of collaterally spaced simple linear conductors all lying in the same plane, the conductors in each of said pairs of conductors being long, relative to the working wave length, and so staggered, longitudinally, that radiation in one pair of opposite critical directions is strengthened, while radiation in the conjugate pair of opposite critical directions is weakened, said pairs of conductors being so staggered and spaced apart in the direction of principal radiation as to make the antenna unidirectional, means coupling the pairs of conductors in phase opposition, and means coupling at least one of the pairs of conductors with radio equipment.

7. A directional antenna system comprising two pairs of collaterally spaced and substantially parallel simple linear conductors all lying in the same plane, each conductor being long, relative to the working wave length, the conductors in each pair being so staggered, longitudinally that radiation in one pair of opposite critical directions is strengthened, while radiation in the conjugate pair of opposite critical directions is weakened, means coupling the conductors in each pair in phase opposition, means for tuning said conductors and coupling means to an overall electrical length of an odd number of half waves, so as to cause standing waves of opposite polarity on the conductors in each pair, said pairs of conductors being so spaced apart in the direction of principal radiation as to make the antenna unidirective, and means coupling at least one of the pairs of conductors with radio equipment.

8. A directional antenna system comprising two pairs of collaterally spaced and substantially horizontally parallel simple linear conductors all lying in the same vertical plane, each conductor being long relative to the working wave length, the conductors in each pair being so staggered, longitudinally, that radiation in one pair of opposite critical directions is strengthened, while radiation in the conjugate pair of opposite critical directions is weakened, means coupling the conductors in each pair in phase opposition, means for tuning said conductors and coupling means to an overall electrical length of an odd number of half waves, so as to cause standing waves of opposite polarity on the conductors in each pair, said pairs of conductors being so spaced apart in the direction of desired radiant action as to make the antenna unidirective, and means coupling at least one of the pairs of conductors with radio equipment.

9. A directive transmission system comprising two pairs of collaterally spaced simple linear conductors all lying in the same plane, the conductors in each of said pairs of conductors being long, relative to the working wave length, and so staggered, longitudinally, that radiation in one pair of opposite critical directions is strengthened, while radiation in the conjugate pair of opposite critical directions is weakened, said pairs of conductors being so staggered and

spaced apart in the direction of principal radiation as to make the antenna unidirectional, means coupling the pairs of conductors in phase opposition, a radio transmitter for energizing the conductors, and means coupling the transmitter to at least one of the pairs of conductors in phase opposition.

10. A directive transmission system comprising two pairs of collaterally spaced and substantially parallel simple linear conductors all lying in the same plane, each conductor being long, relative to the working wave length, the conductors in each pair being so staggered, longitudinally, that radiation in one pair of opposite critical directions is strengthened, while radiation in the conjugate pair of opposite critical directions is weakened, means coupling the conductors in each pair in phase opposition, means for tuning said conductors and coupling means to an overall electrical length of an odd number of half waves, so as to cause standing waves of opposite polarity on the conductors in each pair, said pairs of conductors being so spaced apart in the direction of principal radiation as to make the antenna unidirective, a radio transmitter for energizing the conductors, and means coupling the transmitter to said pairs of conductors in phase quadrature.

11. A directional antenna system including a plurality of unidirectional antennæ lying in spaced parallel planes, each antenna comprising two pairs of collaterally spaced and substantially parallel simple linear conductors lying in a single plane, the conductors being long, relative to the working wave length, the conductors in each of said pairs being so staggered, longitudinally, that radiation in one pair of opposite critical directions is strengthened, while radiation in the conjugate pair of opposite critical directions is weakened, means coupling the conductors in each pair in phase opposition, means for tuning said conductors and coupling means to an overall electrical length of an odd number of half waves, so as to cause standing waves of opposite polarity on the conductors in each pair, said pairs of conductors being so staggered and spaced apart in the direction of principal radiation as to make the antenna unidirectional, and means coupling corresponding pairs of conductors in each of the antennæ in parallel and in proper phase to radio equipment.

12. A unidirectional antenna system including a plurality of unidirectional antennæ lying in spaced parallel vertical planes, each antenna comprising two pairs of collaterally spaced and substantially horizontal parallel simple linear conductors lying in a single plane, said planes being spaced transversely of the antenna so as to sharpen the directivity in azimuth, the conductors being long relative to the working wave length, the conductors in each of said pairs being so staggered, longitudinally, that radiation in one pair of opposite critical directions is strengthened, while radiation in the conjugate pair of opposite critical directions is weakened, means coupling the conductors in each pair in phase opposition, means for tuning said conductors and coupling means to an overall electrical length of an odd number of half waves, so as to cause standing waves of opposite polarity on the conductors in each pair, said pairs of conductors being so staggered and spaced apart in the direction of principal radiation as to make the antenna unidirectional, and means coupling corresponding pairs of conductors in each of the antennæ in parallel and in proper phase to radio equipment.

13. A directive transmission system including a plurality of unidirective antennæ lying in spaced parallel planes, each antenna comprising two pairs of collaterally spaced and substantially parallel simple linear conductors lying in a single plane, the conductors being long, relative to the working wave length, the conductors in each of said pairs being so staggered, longitudinally, that radiation in one pair of opposite critical directions is strengthened, while radiation in the conjugate pair of opposite critical directions is weakened, means coupling the conductors in each pair in phase opposition, means for tuning said conductors and coupling means to an overall electrical length of an odd number of half waves, so as to cause standing waves of opposite polarity on the conductors in each pair, said pairs of conductors being so staggered and spaced apart in the direction of principal radiation as to make the antenna unidirectional, a radio transmitter for energizing said antennæ and means coupling corresponding pairs of conductors in each of said antennæ in parallel and in proper phase to the radio transmitter.

14. A unidirectional short wave antenna comprising four collaterally spaced substantially parallel wires which are long, relative to the working wave length, all lying in a single plane, means for coupling pairs of the wires in phase opposition, means for tuning the pairs of wires to an odd number of half waves in total electrical length so as to cause standing waves of opposite polarity thereon, the wires in each pair being staggered longitudinally so that their ends form the same angle, relative to the transverse axis of the antenna, that the direction of principal radiation makes with the longitudinal axis of the antenna, and spaced apart an odd number of half wave lengths in the direction of principal radiation, the pairs of conductors being so staggered and spaced apart that energy from one pair combines with the energy from the other pair in phase so as to make the antenna unidirectional,

and radio equipment coupled to at least one of the pairs of conductors.

15. A unidirectional short wave antenna comprising four collaterally spaced substantially parallel wires which are long, relative to the working wave length, all lying in a single plane, a pair of trombone slides for coupling together pairs of the wires and for tuning them to an odd number of half waves in total electrical length so as to cause standing waves of opposite polarity thereon, the wires in each pair being staggered longitudinally so that their ends form the same angle, relative to the transverse axis of the antenna, that the direction of principal radiation makes with the longitudinal axis of the antenna, and spaced apart an odd number of half wave lengths in the direction of principal radiation, the pairs of conductors being spaced apart a quarter wave length in the direction of principal radiation, a transmission line a quarter wave in length coupled to the trombone slides at points so spaced that the impedance therebetween matches the impedance of the transmission line, and radio equipment coupled to one of the trombone slides.

16. The method of securing unidirectional electro-magnetic wave propagation which includes producing a standing wave, producing another physically shifted standing wave of opposite polarity, and combining the fields produced by the standing waves whereby propagation of electro-magnetic energy is unidirectional.

17. A directional antenna comprising a collaterally spaced pair of simple linear conductors which are long, relative to the working wave length, and which are so staggered, longitudinally that wave action in one pair of opposite critical directions is strengthened, while wave action in the conjugate pair of opposite critical directions is weakened, and means for energizing said wires in phase opposition.

18. A directional antenna comprising a collaterally spaced pair of simple linear conductors which are long relative to the working wave length, and which are so staggered, longitudinally, that electromagnetic action in one pair of opposite critical directions is strengthened, while electromagnetic action in the conjugate pair of opposite critical directions is weakened, said wires adapted to be energized in phase opposition.

19. A unidirectional antenna comprising spaced linear conductors, means for causing standing waves of different polarity thereon, said conductors being staggered whereby action of the antenna is predominately unidirectional.

20. A directional antenna comprising a collaterally spaced pair of substantially parallel simple linear conductors which are long, relative to the working wave length, and which are so staggered, longitudinally, that wave action in one pair of opposite critical directions is strengthened, while wave action in the conjugate pair of opposite critical directions is weakened, said conductors adapted to be energized in phase opposition, means for actionally coupling the conductors, and means for tuning said conductors and coupling means to an overall electrical length of an odd number of half waves, so as to cause standing waves of opposite polarity on the conductors.

21. A directional antenna comprising two pairs of collaterally spaced simple linear conductors all lying in the same plane, the conductors in each of said pairs of conductors being long, relative to the working wave length, and so staggered, longitudinally, that electro-magnetic action in one pair of opposite critical directions is strengthened, while electro-magnetic action in the conjugate pair of opposite critical directions is weakened, said pairs of conductors being so staggered and spaced apart in the direction of principal electro-magnetic action as to make the antenna unidirectional, means coupling the pairs of conductors in phase opposition, and means coupling at least one of the pairs of conductors with radio equipment.

22. A directional antenna system comprising two pairs of collaterally spaced and substantially parallel simple linear conductors all lying in the same plane, each conductor being long, relative to the working wave length, the conductors in each pair being so staggered, longitudinally, that radiant action in one pair of opposite critical directions is strengthened, while radiant action in the conjugate pair of opposite critical directions is weakened, means coupling the conductors in each pair in phase opposition, means for tuning said conductors and coupling means to an overall electrical length of an odd number of half waves, so as to cause standing waves of opposite polarity on the conductors in each pair, said pairs of conductors being so spaced apart in the direction of desired radiant action as to make the antenna unidirective, and means coupling at least one of the pair of conductors with radio apparatus.

23. A directional antenna comprising a pair of long linear wires connected at adjacent ends to high frequency apparatus and having standing waves of opposite instantaneous polarity thereon, said wires being several wave lengths in length and extending away from and on one side only of said adjacent ends.

24. A directional antenna system comprising a pair of long straight wires and means at adjacent ends of the wires for exciting the wires in phase opposition whereby standing waves of opposite instantaneous polarity are set up on the wires, said wires being several

wave lengths in length at the operating frequency and extending on one side only and away from said adjacent ends.

25. A directive antenna system for propagating or receiving propagated electromagnetic waves comprising a pair of substantially straight conductors, long, relative to the working wave length such that several standing waves at the operating frequency are set up on each conductor, said conductors being arranged so that radiant action occurs in a direction making the same angle with each conductor, and means coupling said conductors in phase opposition, said conductors lying in the same plane and extending away from said coupling means on one side only thereof.

26. A directive antenna system for propagating or receiving electromagnetic waves as claimed in claim 25 wherein a similar pair of conductors are provided, the conductors of said similar pair being arranged parallel to the respective conductors of the first pair whereby the directional effect of the system is augmented.

27. A directive antenna system for propagating or receiving electromagnetic waves as claimed in claim 25 wherein a similar pair of conductors are provided, the conductors of said similar pair being arranged parallel to the respective conductors of the first pair and lying in the same plane as the plane of the first pair whereby the directional effect of the system is augmented.

28. A directive antenna system for propagating or receiving electromagnetic waves as claimed in claim 25 wherein a similar pair of conductors are provided, the conductors of said similar pair being arranged parallel to the respective conductors of the first pair and lying in a plane parallel to the plane of said first pair whereby the directional effect of the system is augmented.

29. A directive antenna system for propagating or receiving propagated electromagnetic waves, comprising a plurality of pairs of conductors arranged in the same plane, respective conductors of the pairs being substantially parallel, each of said conductors being long relative to the working wave length and adapted to have a plurality of standing waves at the working wave length set up thereon, means for connecting the conductors of each pair in phase opposition, the conductors of each pair extending on one side only and away from said connecting means, and, a like number of pairs of conductors arranged in a plane parallel to the plane of said first mentioned plurality of pairs of conductors, the conductors in the like plurality of pairs being arranged parallel to the conductors of said first mentioned plurality of pairs, the conductors of said like pairs being coupled and arranged in a manner similar to the conductors of said first mentioned pairs of conductors, like conductors of the pairs being arranged in parallel fashion, whereby radiant action occurs predominantly in a direction making equal angles greater than zero degrees with each conductor of said system.

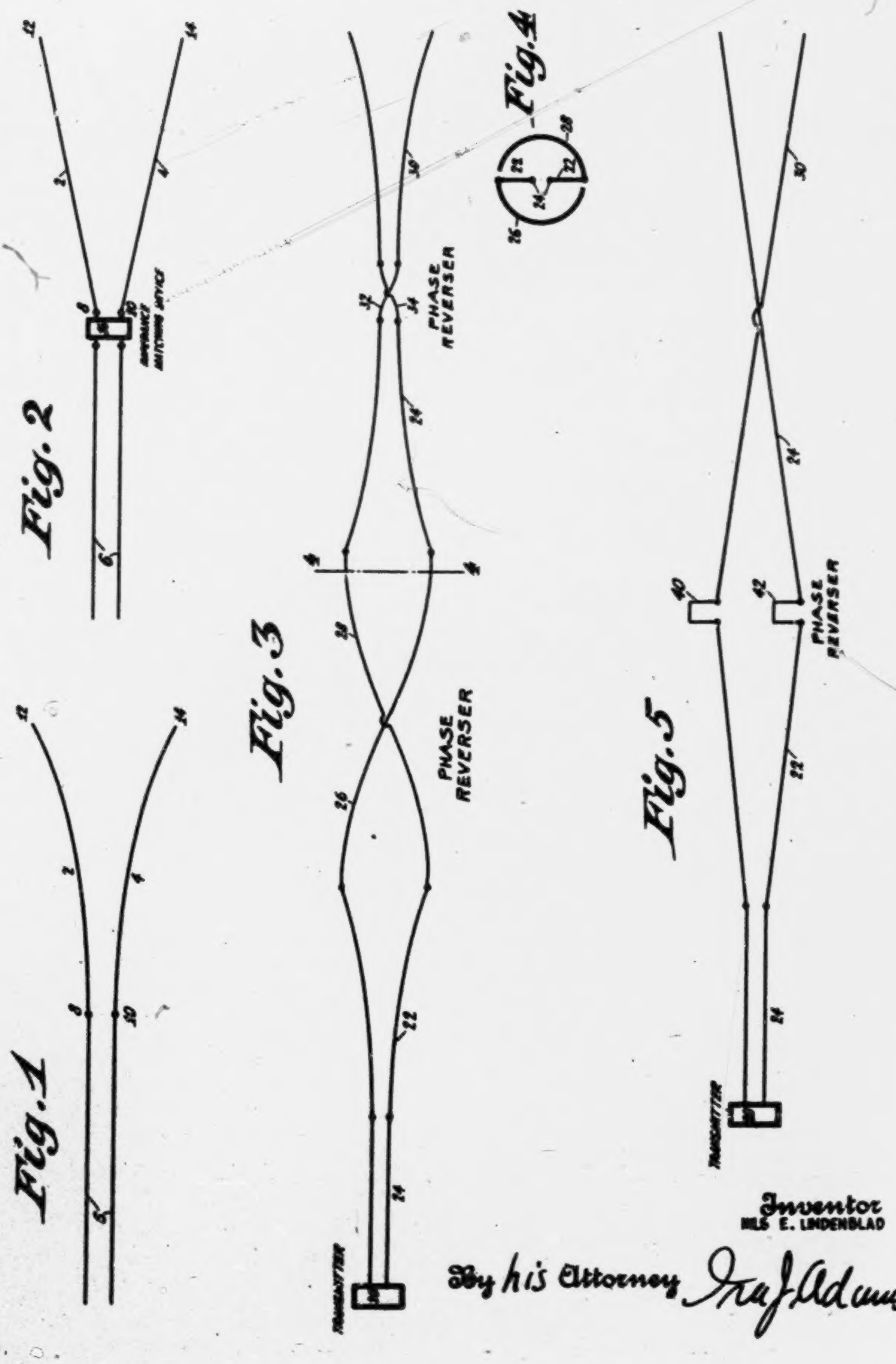
NILS E. LINDENBLAD.

[fols. 671-676] PLAINTIFF'S EXHIBIT No. 4

Sept. 19, 1933. N. E. LINDENBLAD 1,927,522

ANTENNA FOR RADIO COMMUNICATION

Filed Dec. 24, 1928



Inventor
NILS E. LINDENBLAD

By his Attorney Ira J. Adams

Patented Sept. 19, 1933 1,927,522

UNITED STATES PATENT OFFICE

1,927,522

ANTENNA FOR RADIO COMMUNICATION

Nils E. Lindenblad, Port Jefferson, N. Y., assignor to Radio Corporation of America, a corporation of Delaware

Application December 24, 1928
Serial No. 328,147

24 Claims. (Cl. 250—33)

This invention relates to antennas for radio communication.

Short wave antennas suffer from the disadvantage of having to be rather critically tuned to the working frequency, and from the further disadvantage of necessitating the use of some kind of an impedance matching device between the antenna and the transmission line connecting the antenna with the radio equipment. It is an object of my invention to provide an exceedingly simple form of short wave antenna which will operate over a considerable range of frequency, and a further object of my invention is to provide an antenna with which a transmission line may be coupled without the use of intermediate impedance matching devices.

My antenna consists simply of a pair of conductors which at one end are spaced at the spacing of the transmission line, and are coupled thereto, and which gradually diverge to a much wider spacing at their other ends. In effect, therefore, the antenna consists merely of a gradually diverging extension of the conductors of the transmission line, and, in one aspect, the invention resides in the discovery that radiation may be obtained from a transmission line by gradually increasing the spacing between the wires of the line.

The desired radiation takes place in the direction of the axis of the pair of conductors, and is caused by the expansion of the current or the travelling wave of energy in the conductors. Reflection will cause a standing wave, instead of a travelling wave, and result in radiation sideways from the antenna. Despite this, the radiation in the direction of the antenna is still considerably greater than that obtainable from a simple doublet. However, as a refinement the harmonic radiation may be lessened by reducing the standing waves, and to so do is a further object of my invention. It is not feasible, in the case of a transmitting antenna, to avoid standing waves by closing the end of the antenna with a surge resistance, because of the excessive losses which would take place therein.

To lessen the standing wave I reduce the reflected energy by radiating as much of the energy fed to the antenna as possible. To merely increase the dimensions of the antenna is not practicable, for to increase the length without increasing the spacing, that is, to decrease the angle of divergence, does not increase the radiation, and on the other hand, to keep the same angle of divergence necessitates so wide a spacing as to make the antenna structurally inconvenient. To overcome this I employ a plurality of antennas or pairs of diverging conductors, arranged end to end, so as to radiate cumulatively.

I have also found that a pair of converging conductors, like a pair of diverging conductors, will radiate energy, but this radiation is in opposite phase. The antenna may therefore comprise a plurality of pairs of conductors which successively diverge and converge, with means coupling the antennas which reverse the phase of the energy fed thereto.

While the terminology employed in the foregoing description may apply more particularly to a transmitting antenna the structure set forth is equally useful as a receiving antenna.

The invention is further described in the following specification, which is accompanied by a drawing in which

Figure 1 represents one form of my invention;

Figure 2 is a modification employing straight conductors;

Figure 3 shows the use of a plurality of diverging and converging antennas;

Figure 4 is a section of Figure 3 taken on the line 4—4; and

Figure 5 is a modification of Figure 3 showing an alternative form of phase reversing coupling means between the successive antennas.

Referring to Figure 1 it will be seen that the antenna consists of a pair of conductors 2, 4, which are connected to a transmission line 6 at points 8 and 10, which are spaced at the spacing of the transmission line. From the points 8 and 10 the conductors 2 and 4 gradually diverge to a much wider spacing at the ends 12 and 14. The extension of the conductors may be curved, as shown, and one form which is quite successful in operation is an expansion according to an exponential law.

However, in actual practice I find that the refinement of an exponential curve is not essential, and that the conductors 2 and 4 may be straight conductors strung between the points 8 and 12, and the points 10 and 14, under direct tension, and without the use of intermediate shaping or guy wires, and such an arrangement has been indicated in Figure 2.

No impedance matching device is necessary with this antenna, so that in actual practice the antenna is exceedingly simple to erect, it being necessary merely to provide a pair of supporting points 12 and 14 at a desired distance from the termination of the transmission line, and then to continue the conductors of the transmission line directly to the spaced points 12 and 14.

Whatever amount of energy has not been radiated when the travelling wave reaches the end of the antenna is reflected, and thus causes a partial standing wave, which will extend back along the transmission line 6. If the transmission line is short, this may be neglected, but if the transmission line is long, and the antenna is relatively small, so that only a small portion of the energy is radiated, it may prove desir-

able to employ an impedance matching device between the transmission line and the antenna, as is indicated by the impedance matching unit 16, shown in Figure 2.

If, instead, the antenna is made to radiate more energy, the standing wave will incidentally be reduced, and the impedance matching device may be dispensed with. To merely make the antenna much longer, while keeping the same spacing at its open end, does not help, because such a procedure merely slows up the rate of spread of the energy, and does not increase the quantity of energy radiated. On the other hand it ordinarily is not structurally possible to make the antenna considerably longer while maintaining the same angle of divergence of the conductors, owing to the great spacing which would be needed at the open end of the antenna. The same result may be accomplished without these disadvantages by using a plurality of antenna sections arranged end to end. Since a converging antenna is similar in operation to a diverging antenna, except for a reversal in phase, it becomes especially convenient to use a plurality of antenna sections which are successively diverging and converging, and such antennas have been indicated in Figures 3 and 5.

Referring to Figure 3 it will be seen that a transmitter 20 is coupled to a diverging antenna 22 by a transmission line 24. The diverging antenna 22 is followed by a converging antenna 24, which is coupled to the diverging antenna 22 by a pair of conductors 26 and 28. The spacing between these conductors is kept constant, so that practically no radiation takes place therefrom, but at the same time the conductors are electrically crossed in order to reverse the phase of the energy being fed from antenna 22 to antenna 24. For this purpose each of the conductors is supported, at least approximately, in the form of a helix, a feature which is more clearly indicated in the section taken on the line 4—4, and constituting Figure 4. The pitch of the helices should be sufficiently great that the physical distance in space between the antennas 22 and 24 is substantially equal to the distance along the conductors 26 and 28, so that the phase displacement of the wave travelling in space will coincide with that of the energy wave travelling on the conductors 26 and 28. The converging antenna 24 is followed by a diverging antenna 30, and the adjacent ends of the antennas 24 and 30 are coupled by phase reversing coupling conductors 32 and 34.

A modification of the arrangement shown in Figure 3 is indicated in Figure 5, in which a transmitter 20 is coupled by a transmission line 24 to a diverging antenna 22, followed by a converging antenna 24, which in turn is followed by a diverging antenna 30, much as in Figure 3. However, in this case the antennas 22 and 24 are coupled by conductors 40 and 42, which are a half wave in length, in order to reverse the phase of the energy flowing therethrough, and which are bent back upon themselves so as to be substantially nonradiating. The connection between the antennas 24 and 30 is made simply by crossing the conductors as shown, the conductors being separated slightly at the crossing point by an insulator in order to prevent a short circuit between the conductors. In the arrangements shown in Figures 3 and 5 any desired number of antenna sections may be employed.

The plane of polarization of the radiated energy coincides with the plane of the conductors, so that if the conductors are positioned in a horizontal plane the energy is radiated with horizontal polarization, and if the conductors are positioned in a vertical plane the energy is radiated with vertical polarization.

With the conductors in a horizontal plane a standing wave tends to cause side radiation. By locating the conductors in a vertical plane the directivity in azimuth may be maintained regardless of the presence of standing waves, but even in such case it is desirable to prevent waste of the energy radiated thereby, and it is therefore desirable to make the length of the conductors or the number of antenna sections sufficiently great, in accordance with the foregoing instruction, to reduce the standing wave.

In connection with Figures 3 and 5, the desired radiation will, of course, take place in the direction of the axis of the transmission line 24 and the diverging conductors. Taken from another point of view, we can consider merely the upper half of Figures 3 and 5 as being in a vertical plane with its image in the ground; we will then have two serially connected conductors (conductor 26 and the upper antenna leading to transmission line 24 in Figure 3). Radiation will occur substantially in the direction of a line perpendicular to the bisector of the angle between these two conductors.

It will be understood by those skilled in the art that if improved directivity is desired a plurality of these antennas may be employed abreast or in broadside, that is to say, collaterally spaced apart in parallel formation along a line at right angles to the desired direction of communication.

Since the preferred radiation is from the travelling wave, and is due to the expansion of the lines of force between the current charges travelling along the conductors, the divergence should preferably be fairly gradual, and the spacing at the open end, while variable over a great range, should be in the neighborhood of a fifth of the length, and the length of each antenna section should be of the order of magnitude of five to ten waves long.

The antenna is equally suitable both for transmission and reception, the energy in the latter case being collected and converged into the transmission line without the necessity of an impedance matching device.

I claim:

1. The method of directively radiating or collecting high frequency electrical energy which includes directing energy of opposite polarity in a plurality of gradually diverging paths diverging and extending longitudinally in the desired direction of radiant action.

2. The method of unidirectionally radiating or collecting high frequency electrical energy which includes directing energy of opposite polarity in a plurality of gradually converging paths converging and extending longitudinally in the desired direction of radiant action.

3. The method of radiating or collecting high frequency electrical energy which includes directing energy of opposite polarity successively in a plurality of gradually diverging and converging paths and phase reversing the energy as it is directed from one path into another.

4. A uni-directional antenna comprising a gradually diverging pair of conductors excited in phase opposition, diverging and extending longitudinally only in the desired direction of radiant action.

5. A uni-directional antenna comprising a gradually converging pair of conductors excited in phase opposition, converging and extending longitudinally only in the desired direction of radiant action.

6. A uni-directional antenna comprising a pair of conductors excited in phase opposition, extending longitudinally in the desired direction of radiant action, the effective portions of which gradually diverge and converge successively.

7. A uni-directional transmitting antenna comprising a pair of conductors excited in phase opposition, extending longitudinally in the direction of desired transmission, the radiating portions of which gradually diverge and converge successively in the direction of desired transmission.

8. In combination, a two conductor transmission line excited in phase opposition, and an antenna connected thereto extending longitudinally in the direction of transmission, comprising a gradually diverging extension of the conductors of the transmission line at their remote open ends.

9. In combination, a two conductor transmission line excited in phase opposition, and an antenna extending longitudinally in the direction of desired radiant action comprising an open ended pair of conductors which at one end are spaced at the spacing of the transmission line and are coupled thereto, and which gradually diverge to a much wider spacing at their open ends.

10. In combination, a transmission line, and an antenna extending longitudinally in the direction of desired radiant action connected thereto comprising a pair of open ended conductors of the order of magnitude of a number of wave lengths long which are widely spaced at the ends remote from the transmission line and energized with energy of opposite polarity, and spaced at the spacing of the transmission line at their junction therewith.

11. A uni-directional antenna comprising a plurality of pairs of gradually diverging conductors extending longitudinally in the direction of desired transmission and energized in phase opposition.

12. In combination, a transmission line, an antenna connected thereto comprising a pair of conductors a number of wave lengths long which are spaced at the spacing of the transmission line at their junction therewith, and which gradually diverge to a much wider spacing at their remote ends, a second antenna comprising a pair of conductors a number of wave lengths long arranged in extension of the first antenna, and widely spaced at their near ends and closely spaced at their remote ends, another diverging antenna arranged in extension of the converging antenna, and phase reversing means for coupling said antennas together.

13. A uni-directional antenna comprising a diverging pair of conductors excited in phase opposition, diverging only in the desired direction of radiant action.

14. A uni-directional antenna comprising a converging pair of conductors excited in phase opposition, converging only in the desired direction of radiant action.

15. A uni-directional antenna comprising a pair of conductors excited in phase opposition, extending longitudinally in the desired direction of radiant action, the effective portions of which diverge and converge successively.

16. A highly directional antenna system comprising wires which are long relative to the length of the communication wave excited in phase opposition, which first diverge from the excitation end and then converge successively, whereby radiant action occurs predominantly in a direction substantially through the opposite apices of the wires.

17. A system in accordance with claim 16, characterized in this, that said wires are in a single vertical plane.

18. A highly directional antenna system comprising a pair of conductors excited in phase opposition, said wires being long relative to the length of the communication wave and extending in the desired direction of radiant action, the effective portions of which diverge and converge successively.

19. A highly directional antenna system comprising a pair of conductors angularly disposed with respect to each other, said conductors being long relative to the length of the communication wave and open-ended, and means for exciting the conductors in phase opposition whereby radiant action occurs predominantly along the direction of the axis of the conductor system.

20. A unidirectional antenna system comprising a diverging pair of conductors, the said conductors being long relative to the length of the communication wave, and means for producing traveling waves thereon whereby radiation is predominantly along the approximate direction of the length of the conductor system.

21. A system in accordance with claim 20 characterized in this, that said conductors are open-ended and disposed in the same vertical plane.

22. A directional antenna comprising a diverging pair of conductors which are long relative to the working wave length, and means at adjacent ends of said conductors for energizing same in phase opposition, said conductors being arranged to be on the same side of said energizing means and to extend away from said energizing means whereby radiant action occurs predominantly along the approximate direction of the length of the conductor system.

23. A directional antenna comprising a pair of open-ended, diverging conductors which are long relative to the working wave length, and means at adjacent ends of said conductors for energizing same in phase opposition, said conductors being arranged to be on the same side of and to extend away from said energizing means whereby radiant action occurs predominantly in a direction making equal angles greater than zero degrees with reference to said conductors.

24. A highly directional antenna system comprising a pair of electrical conductors which are disposed at an angle with respect to each other and serially connected together, said conductors having an overall length which is long relative to the operating wave length, high frequency apparatus, and means for connecting said apparatus to one end of one of said conductors, the other end of said connected conductor being connected to one end of the second conductor of said pair whereby high frequency energy flows through the entire length of one conductor and continues serially through the entire length of the other conductor, the conductors being adjusted in length and impedance so that radiant action occurs principally in the direction of a line perpendicular to the bisector of the angle between said conductors.

NILS E. LINDENBLAD.

[fols. 677-692] Plaintiff's Exhibit No. 5

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Fig. 1a

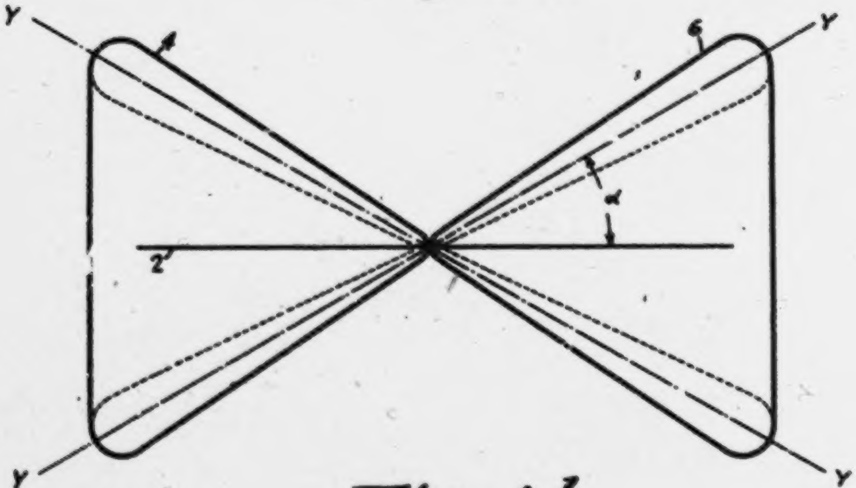

Fig. 1b

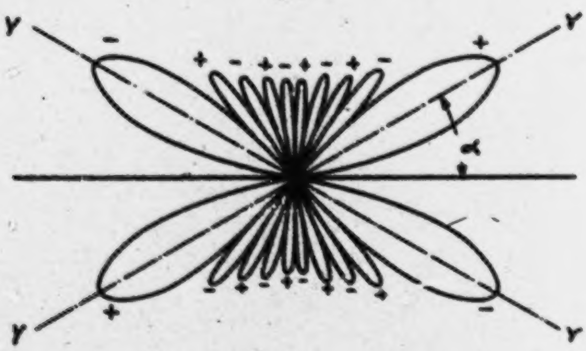

Fig. 2b

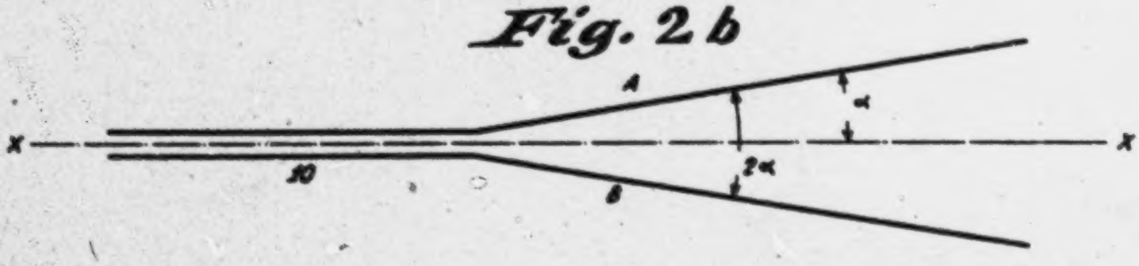

Fig. 2a

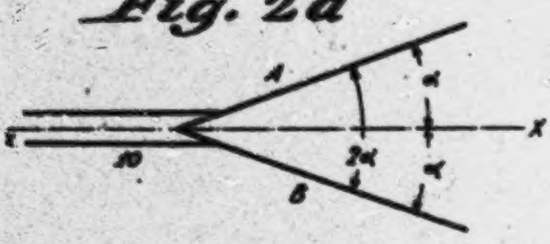

Fig. 2c

INVENTOR
P.S. CARTER
BY [signature]
ATTORNEY

Sept. 18, 1934. P. S. CARTER 1,974,387

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Fig. 3

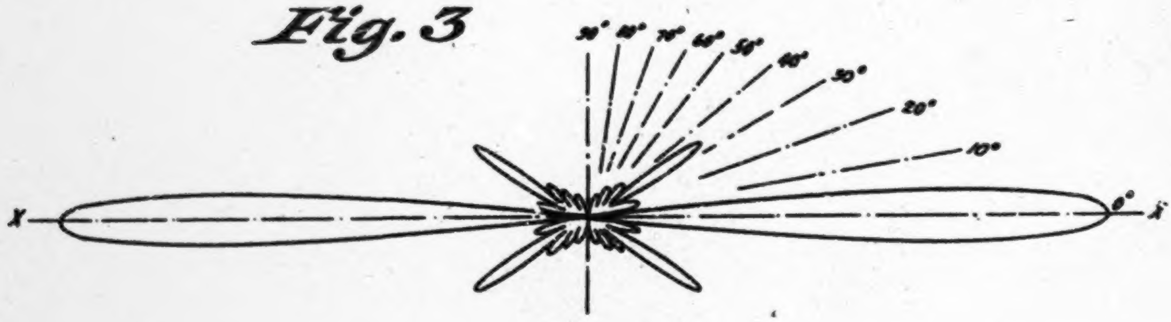

Fig. 4

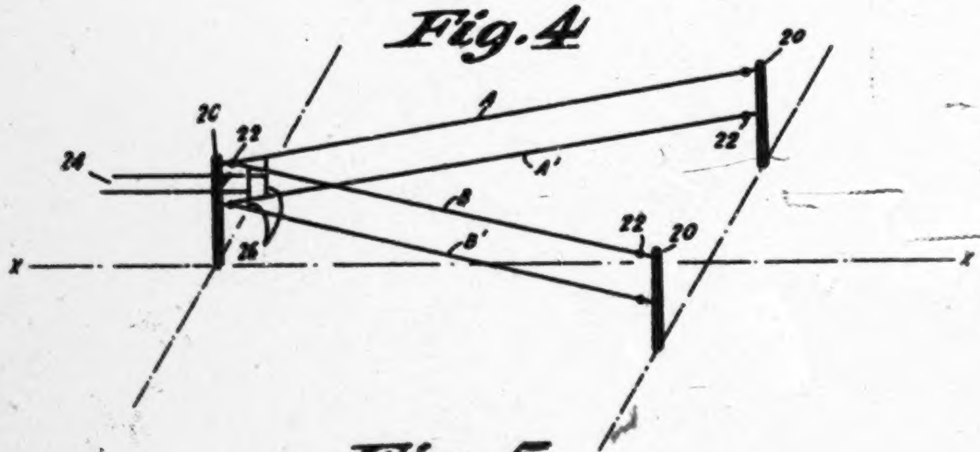

Fig. 5

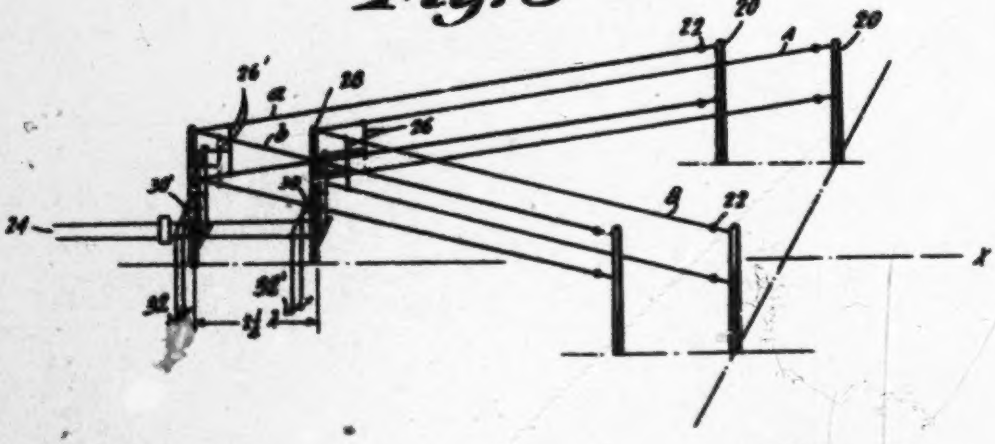

Fig. 7

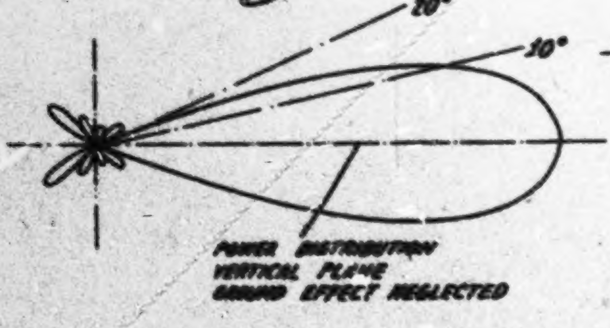

Fig. 6

INVENTOR
P. S. CARTER
BY [signature]
ATTORNEY

Sept. 18, 1934. P. S. CARTER 1,974,387

ANTENNA

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Fig. 8

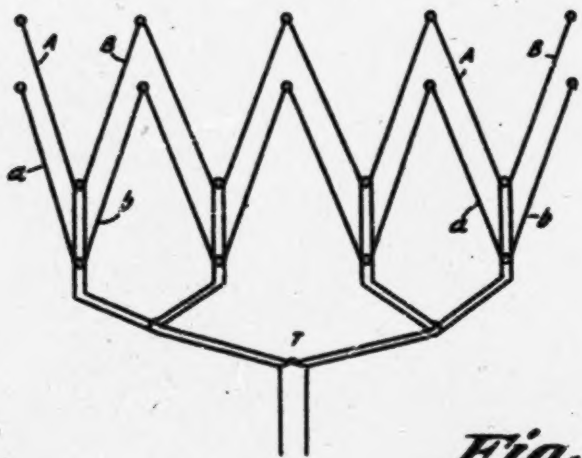
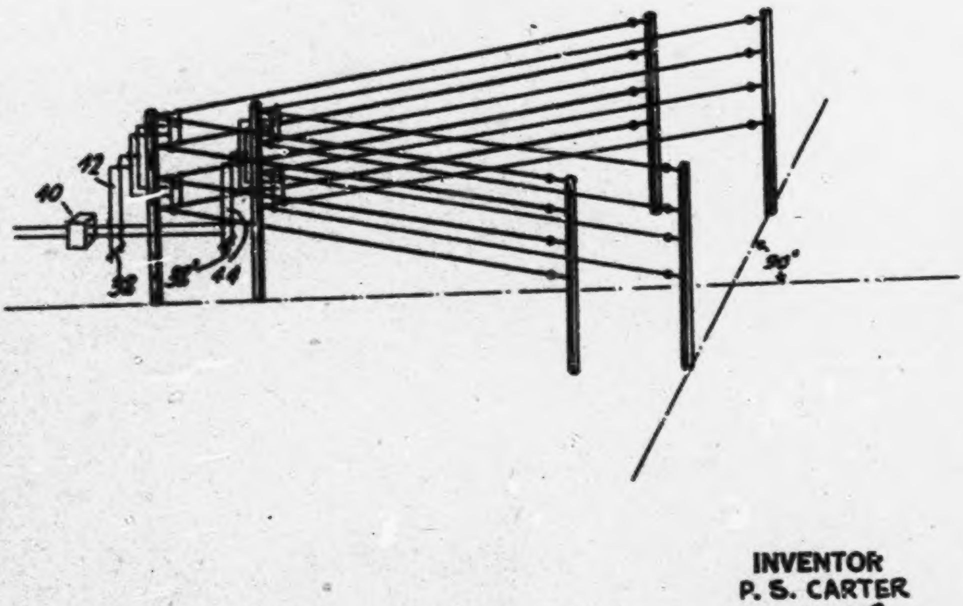


Fig. 10

Fig. 10a

Fig. 9

Fig. 11



INVENTOR
P. S. CARTER
BY H. G. Grover
ATTORNEY

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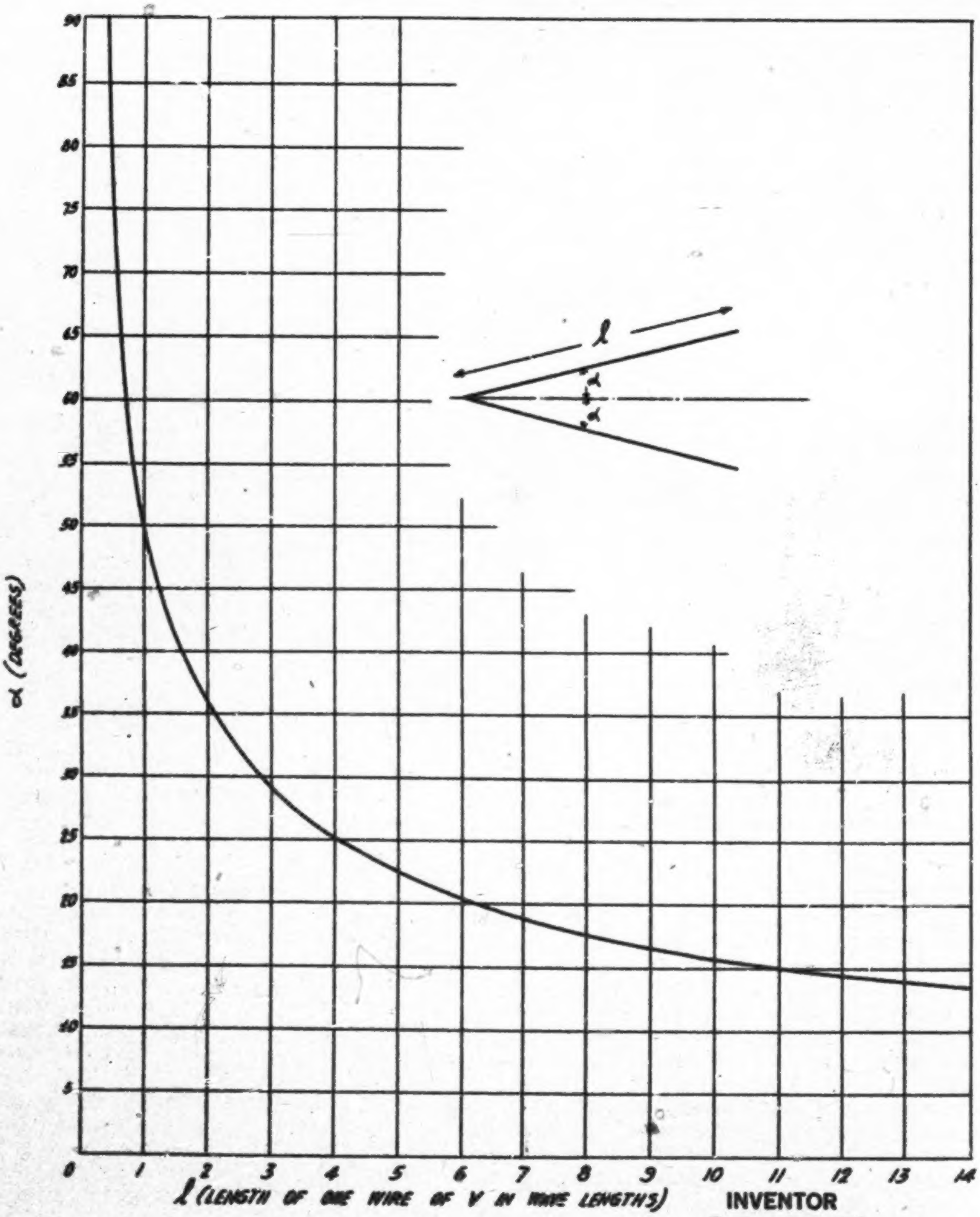
Fig. 12



INVENTOR
P. S. CARTER
BY H. G. Grover
ATTORNEY

Patented Sept. 18, 1934 1,974,387

UNITED STATES PATENT OFFICE

1,974,387

ANTENNA

Philip Staats Carter, Port Jefferson, N. Y., assignor to Radio Corporation of America, a corporation of Delaware

Application June 11, 1930, Serial No. 460,467

41 Claims. (Cl. 250—33)

This invention relates to directive antenna systems, and has for its primary object to provide a simplified and highly efficient antenna system utilizing standing wave phenomena.

It is known that when a wire having a length greater than the operating wave length is excited in such manner that standing waves are produced thereon, radiation will occur principally in the direction of symmetrical cones having their apices at the center of the wire. Such is the case with a wire having a length equal to a plurality of one-half wave lengths at the operating frequency. The radiation pattern produced in such instance appears, in cross section, in the form of symmetrical cones about the wire. The present invention, which makes use of these phenomena, in its most simple aspect employs a pair of open-ended wires energized in phase opposition to have standing waves throughout the length of the wires, the wires having such angular relation with respect to each other as to obtain a highly directional, efficient and simple antenna system. It is proposed to place these wires at an angle with respect to each other so that principal radiation takes place along the bisector of the angle. This angle, in general, corresponds to the angle of the principal cone of radiation of one of the conductors.

Another object of the invention is to disclose the angle for the best directional propagation for open-ended wires of any finite length, preferably longer than the operating wave length, having standing waves thereon and arranged in the manner proposed.

Since a pair of wires of the type above described having standing waves of opposite and instantaneous polarity thereon which are angularly disposed with respect to each other, radiate equally well in two directions, i. e., towards the diverging ends of the wires and towards the converging ends of the wires, such an arrangement is bidirectional.

A further object of the present invention therefore is to provide a unidirectional arrangement. This may preferably be accomplished by placing a similar parallel pair of wires an odd number of quarter wave lengths away from the wires forming the antenna proper in a direction taken along the bisector of the angle formed by the wires. The second pair of wires may be left unenergized or floating, or they may be energized in proper phase such that for one direction radiation cancellation occurs, whereas in the other direction there is a strengthening of propagated electromagnetic waves.

A still further object is to concentrate the beam in planes transverse to the plane of the wires. These transverse planes usually include the vertical plane, since the wires are ordinarily disposed in horizontal planes. This may be effected by placing similar arrangements of wires above or below a given arrangement of wires. To increase horizontal directivity, the arrangements of wires may be duplicated side by side.

Other objects and features will appear in the subsequent detailed description referring to the various embodiments of the invention disclosed in the accompanying drawings.

Figure 1*a* illustrates, generally, the principal conical radiational characteristic of a long conductor upon which standing waves are produced,

Figure 1*b* illustrates in cross section, the radiation characteristic of a wire five wave lengths long,

Figures 2*a*, 2*b* and 2*c* indicate various forms of the fundamental unit of the present invention wherein long linear conductors having standing waves thereon are disposed at an angle such that principal radiation occurs along the direction of the bisector of the angle,

Figure 3 indicates the bidirectional characteristic of one of the units shown in any of the Figures 2*a*, 2*b*, or 2*c*,

Figure 4 illustrates an antenna system for concentrating the directional beam radiated from one of the units shown in Figures 2*a*, 2*b*, and 2*c*,

Figure 5 illustrates the arrangement of a plurality of units such as shown in Figure 2 for obtaining unidirectional propagation,

Figures 6 and 7 illustrate, respectively, the power distribution in the horizontal and vertical planes from one antenna system of particular dimensions of the type shown in Figure 5,

Figure 8 illustrates a broadside arrangement of unidirectional units for further increasing the directivity of a propagated beam of electromagnetic waves,

Figure 9 indicates schematically in plan view, an end-on or in line arrangement of units for increasing the directivity of a beam of waves,

Figures 10 and 10*a* indicate diamond shaped arrangements of units for obtaining unidirectional propagation,

Figure 11 illustrates a preferred form of the invention for concentrating a unidirectional beam of energy horizontally and vertically, when the length of wires is of the order of 6 to 12 wave lengths, and,

Figure 12 is a graph showing the relationship between the length of one of a pair of conductors

and half the angle between them for obtaining maximum radiation along the bisector of said angle. As indicated by the sketch of the antenna system in the upper right hand corner of this figure, this relationship holds most strictly when the wires are of equal length.

In general, as shown in Figure 1*a*, there are two principal hollow cones 4, 6 of radiation about a wire such as indicated by the reference character 2, which is long relative to the working wave length. The cones are symmetrical about the wire 2, and the axis of the cones coincides with that of the radiator 2. For a given length of wire measured in wavelengths, the angle α between the axes Y—Y, of each lobe or ear of the cone which appears as such in cross section, and the wire 2 is constant.

More specifically, a cross section of the solid polar diagram of the radiation from a wire, which wire is a number of wave lengths long and has standing waves thereon, contains as many ears per quadrant as there are wave lengths in the wire. Thus, as shown in Figure 1*b*, there are five ears in each quadrant for a wire five wave lengths long, the principal ears or lobes of radiation occurring along the axes Y—Y. As indicated, the instantaneous directions of the field represented by adjacent ears are reversed.

Now, if it is desired to radiate energy principally in the direction of axis X—X of Figures 2*a*, 2*b*, and 2*c*, the conductors, shown in Figure 1, should be turned an angle α relative to the direction X—X; and, in order to increase still further the directional characteristic along the axis X—X, according to the present invention, two wires are used each of which makes an angle α with the axis X—X on opposite sides of the axis in a fashion such that the axis and the pair of wires lie in a single plane. In directions other than along the axis X—X, addition of radiation from the two wires is imperfect, and at certain angles radiation cancellation will occur: Consequently, a pair of wires disposed at the angle α with respect to the X—X axis will have a radiation characteristic in the plane of the pair of wires of the general type shown in Figure 3.

By considering a long wire the equivalent of a very large number of very short, (Hertz) oscillators and by adding up the field components at any point P having a direction angle θ relative to the axis of the wire, where the point P is a great distance from the wire as compared to the length of the wire such that all lines from point P to any point on the wire are essentially parallel, it can be shown that the field strength H is given by the following proportionality for a conductor an odd number of half wave lengths long:

$$H \propto \frac{\cos\left(n\frac{\pi}{2}\cos\theta\right)}{\sin\theta}$$

The letter "*n*" indicates the number of half wave lengths contained in the wire.

For a wire an even number of half wave lengths long, in similar fashion, the field strength "H" is given by the following proportionality:

$$H \propto \frac{\sin\left(n\frac{\pi}{2}\cos\theta\right)}{\sin\theta}$$

Where *n* as above indicates the number of half wave lengths on the wire.

The value for which the angle θ in either of the above equations makes the expression a maximum value gives the value for the angle α at which each wire of the V should be disposed relative to the direction X—X of desired wave propagation. Obviously the critical value of θ for either of the above equations may readily be determined; its value for wires up to fourteen wave lengths long is given graphically in Figure 12. For practical purposes the empirical formula

$$\alpha = 50.9\left(\frac{l}{\lambda}\right)^{-0.513} \text{ degrees}$$

is sufficiently accurate where l equals the length of the wire and λ the wave length, both in the same units of measurement. Where a pair of wires of substantially equal length are used to form the V antenna of the present invention, they should be spaced apart at an angle substantially equal to twice the angle α as determined in any of the ways described above.

In order to obtain a bidirectional unit having a characteristic such as shown in Figure 3, as already indicated, any of the arrangements shown in Figures 2*a*, 2*b*, or 2*c* may be utilized. The fundamental unit is shown in Figure 2*a* where a transmission line 10 supplies high frequency energy to a pair of wires A, B forming the angle 2 α with each other. The angle α is the angle made by one of the conductors with the X—X axis along which it is desired that the radiators A, B, propagate energy. The conductors A, B, are joined together at their apex which falls in the axis X—X as shown. The wires may be fed intermediate their ends in a fashion similar to that in which a half wave length oscillator is fed intermediate its ends. If desired, as shown in Figure 2*b*, the radiating wires may be terminated on a transmission line 10 instead of being connected together at the apex as shown in Figure 2*a*.

The arrangement shown in Figure 2*c* is preferred since it facilitates tuning of the antenna unit comprising the pair of wires A, B. The transmission line 10 feeds energy to a U-shaped loop 12, the legs of which are short circuited by an adjustable short circuiting strap 14, representing a voltage nodal point. The ends 16 of the loop 12 supply energy obtained from line 10 to the conductors A, B whereby the conductors are excited in phase opposition. Adjustment of impedance is accomplished along the legs of the loop by suitable adjustable tapping points 18 in order that reflection along transmission line 10 may be reduced.

Use of the loop allows of completion of the tuning of the antenna wires by making the total effective tuning length of each wire of the V or radiating unit substantially equal to an odd number of quarter wave lengths. The effective radiating length is the length of wire included in the V only, since the loop itself is substantially nonradiating and can be made to be any length.

When tuning of the V is properly accomplished by the U-loop, the system presents a pure resistive load to the transmission line. By tapping the transmission line to the legs of the U at a suitable distance from the short circuiting strip, the effective resistance of the antenna system can be made equal to the surge impedance of the line, which is a necessary condition for maximum transmission efficiency.

It should be noted that energy should be fed so as to energize the radiators A, B in phase opposition, otherwise at a distant point P along the axis X—X there would be radiation cancellation instead of addition. It is also to be distinctly understood that the unit, so far described, is not

only useful for radiation purposes in a transmitting arrangement but may be utilized equally as well for reception. That is, the antenna system according to the present invention is equally well suited for any type of radiant action whether it be collection of radiation energy or the transmission thereof.

It is to be further understood that the wires of each unit can be of any desired length provided they are placed at the correct angle for their particular length. For best tuning, the total overall length of both of the wires and the U loop terminating them should be effectively an integral number of half wave lengths, although the portion forming the radiation element can be of any length. The law giving the correct angle for lengths between odd and even number of half wave lengths is not given herein due to its complexity but the empirical formula and the curve of Figure 12 will be found accurate for all practical purposes, whether or not the length of wire dealt with corresponds to an integral number of half wave lengths.

In order to prevent undesired high angle radiation, and in order to concentrate the desired beam in elevation, the scheme shown in Figure 4 may be utilized. In Figure 4, pairs of wires A, B and A', B' are placed in parallel horizontal planes and supported by masts 20 and suitably insulated therefrom by suitable insulators 22. Both pairs of wires or units are fed cophasally from a transmission line 24 through conductors 26, the wires of each pair or unit being fed in opposite phase. In order to increase the elevational concentration of radiated energy, the pair A, B and the pair of wires A', B' are placed apart in horizontal planes by a substantial spacing of preferably not less than one-half wave length. The lower pair should be at least one-half wave length above ground. Bidirectional propagation ensues along the axis X—X but in a much more concentrated form relative to the use of a single unit.

The vertical spacing of the units one above the other need not be made an integral number of half wave lengths. For wires whose lengths approach the order of magnitude from 6 to 10 wave lengths, a spacing greater than one-half wave length is preferred.

In practice, where the height of the antenna is limited by economic considerations and wherein it is desired to make ground absorption as low as possible, a good compromise is a half wave length spacing. For transmission of energy having a wave length of 17 or 18 meters, a good practical antenna may be had wherein the lower wires are about three-quarters of a wave length above ground, and the spacing between wires is one-half wave length. Eighty foot poles or masts may be used to support the wires.

In order to obtain a unidirectional radiation characteristic, pairs of parallel units such as shown in Figures 2a, 2b, and 2c may be spaced apart a distance along the axis X—X, which in effect is the bisector of the angle formed by each pair of wires in each unit. This distance may, in the preferred arrangement, be equal to an odd number of quarter wave lengths.

Such a system combined with means for concentrating the beam in a direction traversing the plane of the wires of each unit is shown in Figure 5. That is, Figure 5 illustrates a system such as shown in Figure 4 duplicated in a direction along the X—X axis whereby, in a horizontal plane, a directional characteristic is obtained such as that shown in Figure 6 and, in a vertical plane a power distribution characteristic such as shown in Figure 7.

The system of Figure 5, comprising the pair of wires A, B paralleled by similar pairs *a*, *b* spaced apart along the direction X—X an odd number of quarter wave lengths and, as shown nine-quarters of a wave length behind the apex 28 of wires A, B, is excited so that the wires *a*, *b*, have standing current waves thereon 90 degrees ahead in phase of the standing current waves on wires A, B. Consequently, energy will be propagated principally along the axis X—X towards the diverging ends of the radiators. In order to concentrate the beam of energy so radiated, similar pairs of radiators are placed below the pairs A, B and *a*, *b* in planes suitably spaced from the first mentioned pairs of radiators to obtain the desired vertical or elevational concentration. The lower pairs of radiators are excited cophasally with respect to the upper pairs through conductors 26, 26' fed by transmission line 24. In order to tune the various units, there are provided U-shaped loops 30, 30' which are short circuited by straps at 32, 32', similar to 14 at Figure 2c and as shown in Figure 11.

By exciting wires *a*, *b* 90 degrees lagging relative to radiators A, B, unidirectional propagation may be obtained in an opposite direction, or, towards the converging ends or apices of the units.

If greater concentration of the radiated energy is desired, several systems such as shown in Figure 5, for example, comprising an effective radiating unit A, B and an effective reflecting unit *a*, *b* may be placed in broadside with other units, and the several units excited cophasally. Thus, in Figure 8 each of the radiating units A, B shown in plan view is provided with a reflecting unit *a*, *b*. By means of branched transmission lines, as shown diagrammatically at T, each system is fed cophasally as a result of which an extremely concentrated beam of energy in the plane of the units is transmitted in a direction from the reflecting units towards the radiating units or the reverse, depending upon the relative phase of the standing waves on the units.

The units may be arranged in end-on fashion or coaxially as shown in Figure 9 where each of the units U is spaced apart in the direction of desired propagation. By making the phase difference between each of the units equal to

$$2\pi\frac{S}{\lambda}$$

where S is a spacing of each unit measured along the axis, concentrated unidirectional propagation may be obtained in either direction along the X—X axis depending upon whether or not the standing waves on the succeeding units lag or lead each other by the phase difference given according to the foregoing expression.

Other combinations will readily suggest themselves to those skilled in the art, for example, the units U may be placed diamond shaped fashion such as shown in Figure 10, or, they may be superimposed as shown in Figure 10*a*, the wires of each unit traversing each other.

In order to obtain greater concentration of the radiated beam of energy in a direction traversing the plane of each unit, the systems may be extended in the fashion shown in Figure 11. Here, the system of Figure 5 has been duplicated in a vertical direction, giving increased concentration of the beam in elevation. Energy is fed to the system through an impedance matching device 40 and thence cophasally to the reflecting units

through a suitable connection 42. Energy is similarly fed to the radiating units through a suitable connection 44. By suitable tuning and by suitable spacing of the radiating pairs of wires and reflecting pairs of wires, unidirectional propagation may be obtained in either direction along the bisector of the angle formed by the wires of each pair.

The spacing of the antenna and reflector, of the system shown in Figure 11 where the wires are 6 to 12 wave lengths long, is made preferably nine-quarters of a wave length. For wires longer than ten waves lengths, the preferred form should have a greater spacing between the antenna and reflector such as two and three-quarters or three and one-quarter wave lengths. For wires on the order of three or four wave lengths long, the reflector spacing from the antenna may be one and one-quarter wave lengths or less. In general, as the lengths of wires in terms of wave lengths increase, the reflector and antenna spacing should be increased.

In each of the systems for reception, the transmission line would simply be coupled to a suitable receiver, the antenna being directed upon a transmitting station.

The wires, though preferably placed in horizontal planes may be placed at any desired angle without departing from the scope of this invention, and, during transmission it may often be found desirable to have the plane of the wires tilted away from the earth and towards the direction in which the beam of energy is to be propagated.

By the term "plurality of wave lengths", or "plurality of half wave lengths", or "several half wave lengths", it is not intended that the wires so described shall necessarily be an exact or approximate integral number of such lengths, unless so specified, but rather that each of the wires so described shall be sufficiently long to include the lengths specified.

Having thus described my invention, what I claim is:

1. A directional antenna comprising a pair of angularly disposed linear conductors said conductors being angularly disposed with respect to each other, each of a length including substantially a plurality of half wave lengths, means for exciting the radiators in phase opposition whereby standing waves of opposite instantaneous polarity are formed thereon whereby radiant action of the antenna is predominantly along the direction of the bisector of the angle formed by the conductors, and another pair of conductors parallel and similar to said first mentioned pair of conductors and spaced therefrom an odd number of quarter wave lengths measured in a direction along the bisector of the angle of the conductors.

2. A directional transmitting antenna comprising a pair of angularly disposed linear conductors said conductors being angularly disposed with respect to each other, each of a length including substantially a plurality of half wave lengths and being open-ended; means for exciting the radiators in phase opposition whereby standing waves of opposite instantaneous polarity are formed on the radiators; and, another pair of conductors similar and parallel to said first mentioned pair of conductors and spaced therefrom in a direction along the bisector of the angle of the conductors, an odd number of quarter wave lengths.

3. A directional antenna comprising a pair of angularly disposed linear conductors said conductors being angularly disposed with respect to each other in a horizontal plane, each of a length including substantially a plurality of half wave lengths, means for producing standing waves thereon whereby radiant action of the antenna is predominantly along the direction of the bisector of the angle formed by the conductors, and, another pair of conductors similar and parallel to said first mentioned pair of conductors and spaced therefrom in a direction along the bisector of the angle of the conductors by an odd number of quarter wave lengths.

4. A directional transmitting antenna comprising a pair of angularly disposed linear conductors said conductors being angularly disposed with respect to each other, each of a length including substantially a plurality of half wave lengths and being open-ended and disposed in a horizontal plane; means for exciting the radiators in phase opposition whereby standing waves of opposite instantaneous polarity are formed on the radiators; and, another pair of conductors similar and parallel to said first mentioned pair of conductors and spaced therefrom in a direction along the bisector of the angle of the conductors by an odd number of quarter wave lengths.

5. A directional antenna comprising a pair of angularly disposed linear conductors said conductors being angularly disposed with respect to each other, each of a length including substantially a plurality of half wave lengths, means for producing standing waves thereon whereby radiant action of the antenna is predominantly along the direction of the bisector of the angle formed by the conductors, and, another pair of conductors similar to said first mentioned pair of conductors spaced apart from said first mentioned pair in a direction traversing the planes of each pair.

6. A directional antenna comprising a pair of angularly disposed linear conductors said conductors being angularly disposed with respect to each other, each of a length including substantially a plurality of half wave lengths, means for producing standing waves thereon whereby radiant action of the antenna is predominantly along the direction of the bisector of the angle formed by the conductors; and, another pair of conductors similar to said first mentioned pair of conductors spaced apart from said first mentioned pair, in a direction perpendicular to the plane of the pair of conductors a number of half wave lengths.

7. An antenna comprising parallel pairs of angularly disposed conductors, said conductors being angularly disposed with respect to each other, spaced apart along the direction of the bisector of the angle formed by the conductors an odd number of quarter wave lengths, and, similar pairs of conductors in planes parallel to and spaced apart vertically from the planes of the first mentioned pairs of conductors.

8. A transmitting antenna system comprising parallel pairs of angularly disposed conductors, said conductors being angularly disposed with respect to each other, arranged in a horizontal plane having their apices spaced apart along the direction of the bisector of the angle formed by the conductors an odd number of quarter wave lengths, and similar pairs of conductors disposed in a parallel horizontal plane a vertical distance away from said first mentioned plane, equal to one or more half wave lengths.

9. An antenna system comprising a pair of linear conductors, said conductors being angularly disposed with respect to each other, each substantially an odd number of half wave lengths long and angularly disposed with respect to each other at an angle substantially equal to the angle for which the field strength at a distant point lying in the direction of the bisector is a maximum, said field strength being proportional to

$$\frac{\cos\left(n\frac{\pi}{2}\cos\theta\right)}{\sin\theta}$$

where n is the number of half wave lengths contained in each conductor and θ is the half angle between the wires, and means in circuit with said antenna for exciting the conductors in phase opposition whereby standing waves of opposite instantaneous polarity are formed on the conductors throughout their length.

10. An antenna comprising a pair of linear conductors each substantially an even number of half wave lengths long and disposed with respect to each other at an angle substantially equal to the angle for which the field strength at a distant point lying in the direction of the bisector is a maximum, said field strength being proportional to

$$\frac{\sin\left(n\frac{\pi}{2}\cos\theta\right)}{\sin\theta}$$

where n is the number of half wave lengths contained in said conductor and θ is the half angle between the wires, and means in circuit with said antenna for exciting the conductors in phase opposition whereby standing waves of opposite instantaneous polarity are formed on the conductors throughout their length.

11. An antenna comprising a pair of linear conductors, each substantially an odd number of half wave lengths long and angularly disposed with respect to each other at an angle equal to twice the angle for which the expression

$$\frac{\cos\left(n\frac{\pi}{2}\cos\theta\right)}{\sin\theta}$$

is a maximum, n being the number of half wave lengths contained in each conductor, and, a similar pair of conductors spaced from said first pair by an odd number of quarter wave lengths in a direction along the bisector of the angle of the conductors.

12. An antenna comprising a pair of linear conductors each substantially an even number of half wave lengths long and disposed with respect to each other at an angle substantially equal to twice the angle for which the expression

$$\frac{\sin\left(n\frac{\pi}{2}\cos\theta\right)}{\sin\theta}$$

is a maximum, n being the number of half wave lengths contained in each conductor, and a similar pair of conductors spaced from said first pair by an odd number of quarter wave lengths in a direction along the bisector of the angle of the conductors.

13. An antenna comprising a pair of linear conductors, each substantially an odd number of half wave lengths long and angularly disposed with respect to each other at an angle equal to twice the angle for which the expression

$$\frac{\cos\left(n\frac{\pi}{2}\cos\theta\right)}{\sin\theta}$$

is a maximum, n being the number of half wave lengths contained in each conductor, and a similar parallel pair of conductors away from the first mentioned pair in a direction perpendicular to the planes of the pairs.

14. An antenna comprising a pair of linear conductors each substantially an even number of half wave lengths long and disposed with respect to each other at an angle substantially equal to twice the angle for which the expression

$$\frac{\sin\left(n\frac{\pi}{2}\cos\theta\right)}{\sin\theta}$$

is a maximum, n being the number of half wave lengths contained in each conductor, and a similar pair of conductors away from the first mentioned pair in a direction perpendicular to the planes of the pairs.

15. An antenna comprising a pair of relatively long conductors disposed with respect to each other at an angle substantially equal to twice

$$50.9\left(\frac{l}{\lambda}\right)^{-0.513}$$

degrees, l being the length of the wire and λ the operating wave length in like units, and means in circuit with said antenna for exciting the conductors in phase opposition whereby standing waves of opposite instantaneous polarity are formed on the conductors throughout their length.

16. An antenna comprising a pair of relatively long conductors disposed with respect to each other at an angle substantially equal to twice

$$50.9\left(\frac{l}{\lambda}\right)^{-0.513}$$

degrees, and, a similar parallel pair of conductors spaced an odd number of quarter wave lengths away from said first mentioned pair along the bisector of the angle of the conductors, l being the length of each wire and λ being the operating wave length in like units.

17. An antenna comprising pairs of long conductors, the conductors of each pair disposed with respect to each other at an angle substantially equal to twice

$$50.9\left(\frac{l}{\lambda}\right)^{-0.513}$$

degrees, and the pairs being placed in parallel planes substantially an odd number of half wave lengths apart, l being the length of each wire and λ being the operating wave length in like units.

18. An antenna comprising pairs of relatively long conductors the conductors of each pair being disposed with respect to each other at an angle substantially equal to twice

$$50.9\left(\frac{l}{\lambda}\right)^{-0.513}$$

degrees the apices of each pair being separated along the direction of the bisector of the angle formed by the conductors by an odd number of quarter wave lengths; and, similar pairs of conductors in a substantially parallel plane spaced apart from said first pairs, l being the length of each wire and λ being the operating wave length in like units.

19. An antenna arrangement comprising a pair of diverging linear conductors angularly disposed with respect to each other, another pair of angularly disposed diverging conductors similar to said first mentioned pair and spaced apart from said first pair in a direction along the bisector of the angle of the conductors, both said pairs of angularly disposed conductors being arranged to form opposite angles of a four sided plane figure, the conductors of each pair being excited in phase opposition whereby radiant action occurs principally in the plane of said conductors and along the direction of said bisector.

20. A diamond-shaped antenna arrangement comprising a pair of V-shaped antennæ arranged to form a parallelogram, and means for connecting the apex of each V antenna to high frequency apparatus whereby the legs of each V which lie alongside each other are excited in phase opposition so that radiant action occurs principally in the plane of the V-shaped antennæ and principally in a direction along a line joining the apices of said V-shaped antennæ.

21. An antenna system comprising a pair of linear conductors angularly disposed with respect to each other, each of a length including substantially a plurality of one-half wave lengths and being open-ended, another similar pair of angularly disposed linear conductors also of a length including a plurality of one-half wave lengths and being open-ended, both of said pairs being so arranged that the open ends of one pair point in a substantially opposite direction with respect to the open ends of the other pair and the acute angles formed by said pairs face one another, and means for exciting the radiators of each pair in phase opposition whereby standing waves of opposite instantaneous polarity are formed on the radiators.

22. A directional transmitting antenna arrangement comprising a pair of V-shaped antennæ arranged to form a parallelogram, and means for exciting the radiators of each pair in phase opposition whereby standing waves of opposite instantaneous polarity are formed on the radiators whereby radiant action occurs principally in the plane of said radiators and principally along a line joining the apices of said V-shaped antennæ.

23. A directional antenna arrangement comprising a pair of open-ended V-shaped antennæ arranged in a horizontal plane such that the open ends of each pair point in opposite directions with respect to the other pair, and means for connecting the apex of each V antenna to high frequency apparatus whereby radiant action occurs principally in the plane of the V-shaped antennæ and principally in a direction corresponding to the line joining the apices of said V-shaped antennæ.

24. A directional antenna arrangement comprising a pair of open-ended V-shaped antennæ arranged such that the acute angle formed by the individual conductors of each pair of antennæ face each other and the open ends of each pair point in different directions, and means for connecting the apex of each V antenna to high frequency apparatus whereby radiant action occurs principally in the plane of the V-shaped antennæ and principally in a direction corresponding to a line joining the apices of said V-shaped antennæ.

25. A directional antenna arrangement comprising a pair of V-shaped antennæ arranged in such manner that the acute angle formed by the individual conductors of each pair face each other, and means for connecting the apex of each V antenna to high frequency apparatus whereby radiant action occurs principally in the plane of the radiators and principally in a direction corresponding to a line joining the apices of said V-shaped antennæ.

26. A directional antenna comprising a pair of linear conductors angularly disposed with respect to each other and placed in a plane at an angle to the horizontal, said plane extending in the desired direction of transmission, each conductor being of a length including substantially a plurality of one-half wave lengths, means for producing standing waves thereon whereby radiant action of the antenna is predominantly along the direction of the bisector of the angle formed by the conductors, and another pair of conductors similar and parallel to said first mentioned pair of conductors and spaced therefrom in a direction along the bisector of the angle of the conductors by an odd number of one-quarter wave lengths.

27. A directional transmitting antenna comprising a pair of linear conductors angularly disposed with respect to each other, each of a length including substantially a plurality of one-half wave lengths and being open-ended, and disposed in a plane at an angle from the horizontal, said plane extending in the desired direction of transmission, means for exciting the radiators in phase opposition whereby standing waves of opposite instantaneous polarity are formed on the radiators, and another pair of conductors similar and parallel to said first mentioned pair of conductors and spaced therefrom in a direction along the bisector of the angle of the conductors by an odd number of one-quarter wave lengths.

28. A directional transmitting antenna comprising a plurality of pairs of linear conductors, the conductors of each pair being angularly disposed with respect to each other, each conductor being of a length including substantially a plurality of one-half wave lengths and being open-ended, said plurality of pairs being disposed in a horizontal plane along the bisector of the angle of the conductors, means for exciting the two radiators of each pair in phase opposition whereby standing waves of opposite instantaneous polarity are formed on the radiators of each pair, and means for feeding the successive pairs of radiators so that the currents in the successive radiators of each pair differ in phase by an angle $2\pi S/\lambda$ where S is the spacing along the bisector and λ the wave length.

29. A directional transmitting antenna comprising a plurality of pairs of linear conductors, the conductors of each pair being angularly disposed with respect to each other, each conductor being of a length including substantially a plurality of one-half wave lengths and being open-ended, said plurality of pairs being disposed in a plane at an angle from the horizontal, said plane extending in the desired direction of transmission, means for exciting the two radiators of each pair in phase opposition whereby standing waves of opposite instantaneous polarity are formed on the radiators of each pair, and means for feeding the successive pairs of radiators so that the currents in the successive radiators of each pair differ in phase by an angle $2\pi S/\lambda$ where S is the spacing and λ the wave length.

30. A broadside directional antenna comprising a pair of linear conductors angularly disposed with respect to each other, another pair of angu-

larly disposed linear conductors arranged adjacent and in the same plane with said first pair so that said two pairs are side by side and have their acute angles opening in the same direction, and means for producing standing waves thereon whereby radiant action of the antenna is predominantly along the direction of the bisectors of the angles formed by the conductors of each pair for effecting beam concentration.

31. A broadside directional antenna comprising a pair of linear conductors angularly disposed with respect to each other in a horizontal plane, another pair of angularly disposed linear conductors arranged adjacent and in the same plane with said pair so that said two pairs are side by side and have their acute angles opening in the same direction, said pairs being arranged to be excited in phase opposition whereby standing waves of opposite instantaneous polarity are formed thereon.

32. A directional transmitting antenna comprising a pair of linear conductors angularly disposed with respect to each other, each of a length including substantially a plurality of half wave lengths and being open-ended, a transmission line, a pair of vertical connections extending from said pair of conductors to said transmission line, and means in circuit with said transmission line for exciting the conductors in phase opposition whereby standing waves of opposite instantaneous polarity are formed on the conductors, another pair of conductors substantially similar and parallel to said first mentioned pair and spaced therefrom in a direction along the bisector of the angle of the conductors, and a pair of vertical connections in circuit with said last pair of conductors, and joining said last pair with said transmission line.

33. A directional transmitting antenna comprising a pair of linear conductors angularly disposed with respect to each other, each of a length including substantially a plurality of half wave lengths and being open-ended, a transmission line, a pair of vertical connections extending from said pair of conductors to said transmission line, and means in circuit with said transmission line for exciting the conductors in phase opposition whereby standing waves of opposite instantaneous polarity are formed on the conductors, another pair of conductors substantially similar and parallel to said first mentioned pair and spaced therefrom in a direction along the bisector of the angle of the conductors, and a pair of vertical connections in circuit with said last pair of conductors, said two pairs of vertical connections being joined together by a pair of horizontal conductors.

34. An antenna arrangement comprising a pair of conductors each of a length including several half wave lengths at the operating frequency, said conductors being angularly disposed at an acute angle with respect to each other, each conductor making the same angle with, but lying on opposite sides of a line representing the desired direction of radiant action, and a U-shaped metallic circuit having legs substantially parallel to each other connected between substantially opposite points on said angularly disposed conductors, which points are relatively close together.

35. An antenna arrangement comprising a pair of conductors each of a length including several half wave lengths at the operating frequency, said conductors being angularly disposed with respect to each other, each conductor making the same angle with, but lying on opposite sides of a line representing the desired direction of radiant action, and a circuit having conductors substantially parallel to each other connected between substantially opposite points on said angularly disposed conductors, which points are relatively close together, and means for effectively connecting together for high frequency currents, similarly located points on each of said parallel conductors.

36. An antenna arrangement comprising a pair of conductors each of a length including several half wave lengths at the operating frequency, said conductors being angularly disposed with respect to each other, each conductor making the same angle with, but lying on opposite sides of, a line representing the desired direction of radiant action, a U-shaped circuit having legs substantially parallel to each other connected between substantially opposite points on said angularly disposed conductors, which points are relatively close together, and a transmission line connected to the legs of said U-shaped circuit and to said angularly disposed conductors for energizing said conductors in phase opposition.

37. A directional antenna comprising a pair of angularly disposed substantially straight conductors, said conductors being angularly disposed with respect to each other, each conductor being of a length including a plurality of half wave lengths at a desired operating frequency, means for exciting the conductors in phase opposition whereby standing waves of opposite instantaneous polarity are formed thereon whereby radiant action of the system formed by said angularly disposed linear conductors is predominantly along the direction of the bisector of the angle formed by the conductors, another pair of conductors parallel and similar to said first mentioned pair of conductors, and a substantially radiationless transmission line, not less than a quarter wave length long at the desired operating frequency, joining substantially opposite points on said pairs of conductors, the points on each pair being relatively close together.

38. A directional antenna comprising a pair of straight conductors angularly disposed with respect to each other, each conductor being of a length including a plurality of wave lengths at the operating frequency and being electrically open-ended at their most widely separated ends, means for exciting said conductors in phase opposition whereby standing waves of opposite instantaneous polarity are formed thereon, and another pair of open-ended conductors similar and parallel to said first mentioned pair of conductors and being spaced therefrom in a direction along the bisector of the angle of the conductors such that radiant action of said pairs of conductors is substantially unidirectional.

39. A directional antenna comprising a pair of straight conductors angularly disposed with respect to each other, each conductor being of a length including a plurality of half wave lengths at the operating frequency, said conductors being electrically open-ended at their most widely separated ends, another pair of open-ended conductors similar and parallel to said first mentioned pair of conductors and spaced therefrom in a direction along the bisector of the angle of the conductors, and a substantially radiationless transmission line connected between points on said pairs of conductors, the points chosen on each pair being relatively close together, said transmission line being not less than a quarter

wave length long at the desired operating frequency.

40. A directional antenna comprising two pairs of conductors, the conductors of each pair being substantially straight and being arranged so as to form substantially a V, each conductor of each of said pairs of conductors being of a length including a plurality of wave lengths at the desired operating frequency, the most remote ends of the conductors of each pair being electrically open-ended, both pairs of conductors lying in the same plane and symmetrically about a line representing a desired direction of radiant action.

41. A directional antenna comprising two pairs of conductors, the conductors of each pair being substantially straight and being arranged so as to form substantially a V, each conductor of each of said pairs of conductors being of a length including a plurality of wave lengths at the desired operating frequency, the most remote ends of the conductors of each pair being electrically open-ended, both pairs of conductors lying in the same plane and symmetrically about a line representing a desired direction of radiant action, and a substantially radiationless transmission line not less than a quarter wave length long connected between similar points on said pairs of conductors, the points taken on each pair of conductors being close together relative to the electrical open ends of said conductors.

PHILIP STAATS CARTER.

PLAINTIFF'S EXHIBIT No. 7

DESCRIPTION OF SAYVILLE ANTENNA NO. 8

The defendant's WMZ-20 antenna system at Sayville, Long Island, New York, had, at the time of the commencement of this suit, substantially the arrangement and dimensions shown in the drawing hereto annexed and marked "Exhibit A, WMZ-20 Antenna System". This antenna system, at the time above stated, was being utilized by defendant in the transmission of commercial messages for pay to San Francisco, California (bearing approximately N 281° E), and Chicago, Illinois (bearing approximately N 278° E), on a wave-frequency of 5990 kilocycles which corresponds to a wave-length of 50.08 meters (164.3 feet). Following is a description of this antenna system as it existed at the time above stated (the reference characters being shown on the said diagram):

The antenna system comprises two V-type antennae (ACBD and A'C'B'D', respectively), lying in the same horizontal plane 80 feet above the ground surface. The length of each of the four antenna wires AC, BD, A'C', and B'D' is 657 feet. The adjacent ends C, D, of the wires constituting one V antenna are 15 inches apart and are connected through a pair of wires, CI and DJ, respectively, to another pair of wires leading from the points I and J, respectively, to the transmitter. The adjacent ends, C',D', of the wires constituting the other V antenna are 15 inches apart and are connected through a pair of wires C'I'I and D'J'J, respectively, to the said pair of wires leading from the points I and J, respectively, to the transmitter. The wires CI and DJ are vertical. The pair of wires C'I'I and D'J'J comprise

a vertical section C'I' and D'J' and an horizontal section I'I and J'J. The wires CI, C'I'I, and the wire from I to the transmitter are spaced 12" from the wires DJ, D'J'J, and the wire from J to the transmitter, respectively. All of the said wires, as well as the antenna wires, are #6 copper-clad steel wire.

The wires leading from the points I, J to the transmitter are each approximately 800 feet long; the said wires and, therefore, the two wires of each antenna are fed in phase opposition. The vertical wires CI, DJ, C'I', and D'J' are each approximately 42 feet lon and the horizontal wires I'I and J'J are each approximately 123 feet long.

The bearing of the horizontal line bisecting the angle between the wires AC and BD and the angle between the wires A'C' and B'D', taken from the apices toward the open ends, is approximately 282° east of true north.

Connected to the wires leading from the points I, J to the transmitter, at points K and L approximately 12 feet from I and J, are two parallel wires, KM and LN, each approximately 15 feet long, which wires KM and LN are open ended. Similarly, connected to the vertical wires CI and DJ, at points E and F approximately 27 feet from C and D, are two parallel wires EG and FH; the wires EG and FH are closed by the cross-connection GH located approximately 10 feet from the points E, F. Similarly, connected to the vertical wires C'I' and D'J', at points E' and F' approximately [illegible] feet from C' and D', are two parallel wires E'G' and F'H'; the wires E'G' and F'H' are closed by the cross-connection G'H' located approximately 9 feet from the points E', F'. The wires KM, EG, and E'G' are spaced 12" from the

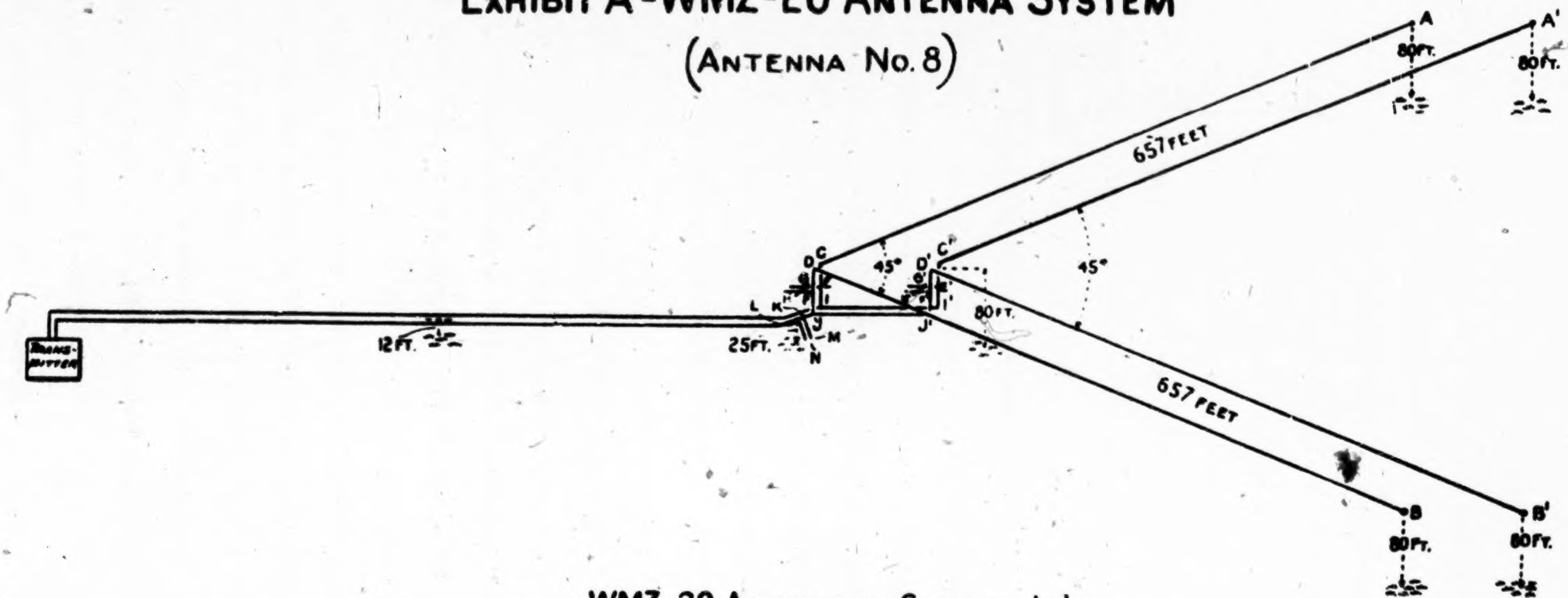
wires LN, FH, and F'H', respectively. All of the said wires, as well as the cross-connections GH and G'H', are #6 copper-clad steel wire.

The antenna wires, together with the wires from the transmitter to the antennae, the positions of the three pairs of parallel wires and of the two cross-connections, and the length of the parallel wires KM, LN, were so adjusted, when the antenna system was installed, that an approximate impedance match was provided at each of the pairs of points KL, EF, and E'F', whereby energy is efficiently transferred across each of said pairs of points and reflection of waves toward the transmitter from each of said pairs of points is reduced. Waves are reflected intentionally between the points IJ, and MN, via KL, as well as between the antenna ends, AB, and GH, via EF, and the antenna ends, A'B', and G'H', via E'F'. The reflected waves are reduced as above stated on the wires EI, FJ, E'I'I, and F'J'J and on the wires leading from points KL to the transmitter. The antenna system is directive and the angle between the wires AC and BD and between A'C' and B'D' is 45°.

The dimensional data set forth in the foregoing description, together with alternative statements of certain dimensions in terms of wave length, are tabulated in Exhibit G.

Exhibit A - WMZ-20 Antenna System

(Antenna No. 8)



WMZ-20 Antenna at Sayville, L.I.

5990 Kilocycles Frequency or

Wavelength - λ - 50.08 meters (164.3 feet)

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PLAINTIFF'S EXHIBIT No. 8

DESCRIPTION OF SAYVILLE ANTENNA NO. 1C

The defendant's WKT antenna system at Sayville, Long Island, New York, had, at the time of the commencement of this suit, substantially the arrangement and dimensions shown in the drawing hereto annexed and marked "Exhibit B, WKT Antenna System". This antenna system, at the time above stated, was being utilized by defendant in the transmission of commercial messages for pay to San Francisco, California (bearing approximately N 281° E), on a wave-frequency of 16,370 kilocycles, which corresponds to a wavelength of 18.326 meters (60.13 feet). Following is a description of this antenna system as it existed at the time above stated (the reference characters being shown on the said diagram):

The antenna system comprises two V-type antennae (ACBD and A'C'B'D', respectively), lying in the same horizontal plane 80 feet above the ground surface. The length of each of the four antenna wires AC, BD, A'C', and B'D' is 431 feet. The adjacent ends, C, D, of the two wires constituting one V antenna are connected by wires, each 1.58 feet long, to the upper ends E, F, of two vertical copper tubes each 15.03 feet long, having an outside diameter of one inch, and spaced 9.5 inches apart, center to center; the lower ends G, H, of these tubes are connected direct to the junction points I, J. The distance from the points C, D, to the points, I, J, is 16.58 feet. Another pair of parallel wires 12" apart leads from the points I, J, to the transmitter. The adjacent ends C',D' of the wires constituting

the other V antenna are connected by wires, each 1.58 feet long, to the upper ends E', F', of two vertical copper tubes each 15.03 feet long, having an outside diameter of one inch, and spaced 7.25 inches apart, center to center; the lower ends G',H', of these tubes are connected direct to the points I',J', and thence by horizontal wires, spaced 12" apart and each 135 feet long, to the junction points I, J. The distance from the points C',D', to the points I',J', is 16.58 feet. The points C, D and C',D' on the antennae are separated, respectively, 12 and 10 inches. All of the wires, including the antenna wires, are #6 copper-clad steel wire.

The wires leading from the points I,J to the transmitter are each approximately 221 feet long; the said wires and, therefore, the two wires of each antenna, are fed in phase opposition.

The bearing of the horizontal line bisecting the angle between the wires AC and BD and the angle between the wires A'C' and B'D', taken from the apices toward the open ends of the V's, is approximately 282° East of true North.

Connected to the wires leading from the points I,J to the transmitter, at points K and L 4.5 feet from I and J, are two parallel wires, KM and LN, each 5.3 feet long and spaced 12" apart, which wires KM and LN are open ended.

The antenna wires, together with the conductors leading from the transmitter to the antennae, the position and length of the pair of wires KM and LN, and the length, diameter, and position of the copper tubes were so selected and adjusted, when the antenna system was installed, that an

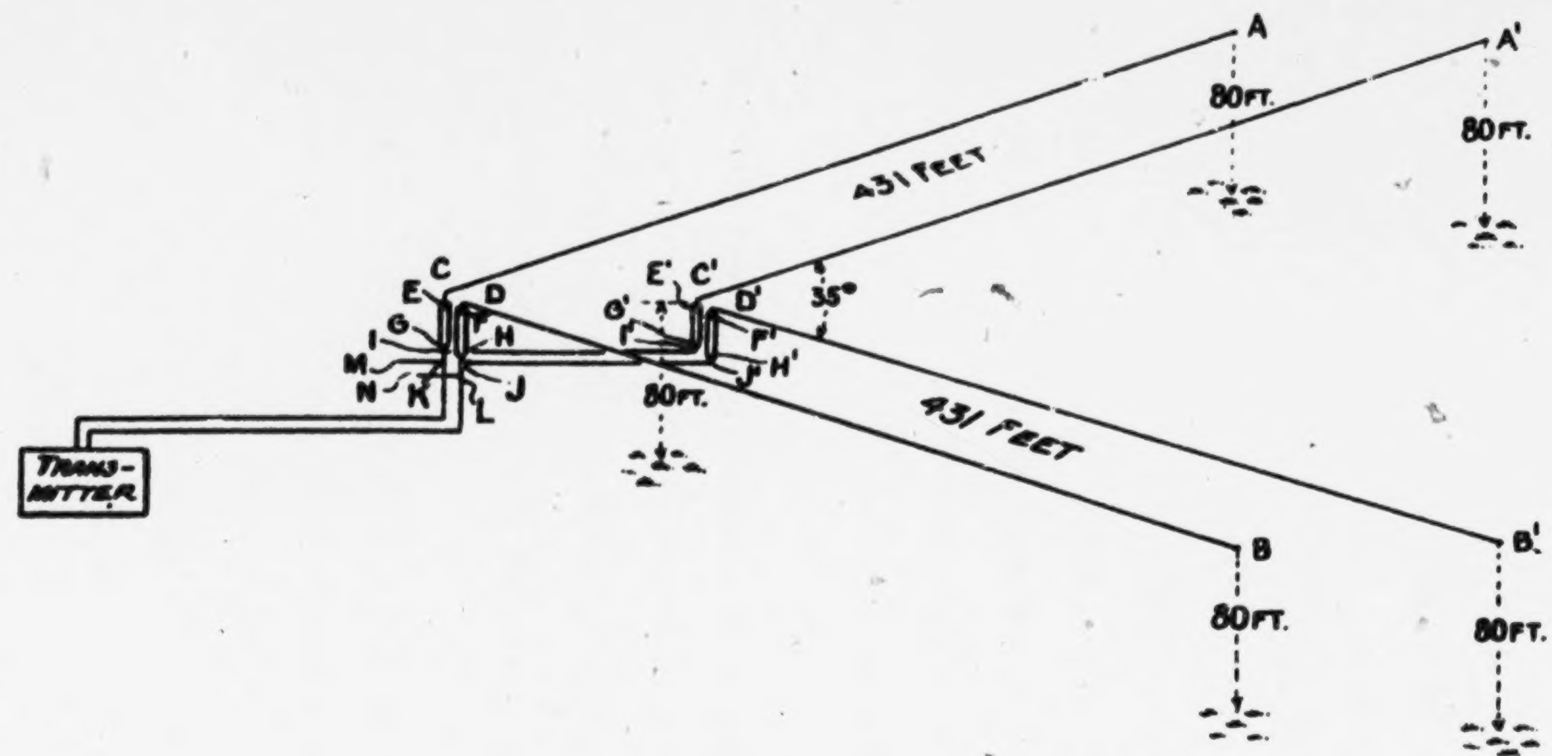
approximate impedance match was provided at each of the pairs of points KL, GH and G'H', whereby energy is efficiently transferred across each of said pairs of points and reflection of waves toward the transmitter from KL and from G'H' is reduced. Waves are reflected intentionally between the points I,J, and M,N, via K,L, as well as from the antenna ends A,B, toward the points E,F, and from the antenna ends A',B', toward the points E',F'. The reflected waves are reduced as above stated on the wires G'I'I, and H'J'J and on the wires leading from points K,L, to the transmitter. The antenna system is directive, and the angle between the wires AC and BD and between A'C' and B'D' is 35°.

The dimensional data set forth in the foregoing description, together with alternative statements of certain dimensions in terms of wave lengths, are tabulated in Exhibit G.

Other antennae Nos. 4, 5, and 6 were, at the time of the commencement of this suit, constructed and adjusted like No. 10 described in the foregoing, except as to the specific differences shown by the tabulation in Exhibit G.

Exhibit B–WKT Antenna System

(Antenna No. 10)



WKT Antenna at Sayville, L.I.

16,370 Kilocycles Frequency or

Wavelength – λ – 18.326 meters (60.13 feet)

8/4

PLAINTIFF'S EXHIBIT No. 9

DESCRIPTION OF SAYVILLE ANTENNA NO. 1

The defendant's WIU antenna system at Sayville, Long Island, New York, had, at the time of the commencement of this suit, substantially the arrangement and dimensions shown in the drawing hereto annexed and marked "Exhibit C, WIU Antenna System". This antenna system, at the time above stated, was being utilized by defendant in the transmission of commercial messages for pay to San Francisco, California (bearing approximately N 281° E) on a wave-frequency of 10,170 kilocycles, which corresponds to a wavelength of 29.5 meters (96.79 feet). Following is a description of this antenna system as it existed at the time above stated (the reference characters being shown on the said diagram):

The antenna system comprises two V-type antennae (ACBD and A'C'B'D', respectively), lying in the same horizontal plane 80 feet above the ground surface. The length of each of the four antenna wires AC, BD, A'C', and B'D', is 601 feet. The adjacent ends, C, D, of the two wires constituting one V antenna are connected by wires, each 1.58 feet long, to the upper ends, E,F, of two vertical copper tubes each 24.2 feet long, having an outside diameter of one inch, and spaced 7.5 inches apart, center to center; the lower ends G,H, of these tubes are connected by wires seven inches long to the junction points I, J. The distance from points C, D, to points I, J, is 26.33 feet. Another pair of parallel wires 12" apart leads from the points I, J, to the transmitter. The adjacent ends, C', D', of the wires constituting the other V antenna are connected by wires, each 2.08 feet long, to the upper ends, E', F', of two vertical

copper tubes each 24.2 feet long, having an outside diameter of one inch, and spaced 5.5 inches apart, center to center; the lower ends, G',H', of these tubes are connected direct to the points I',J', and thence by horizontal wires, spaced 12" apart and each 72.67 feet long, to the junction points I, J. The distance from points C',D', to points I',H', is 26.33 feet. The points C, D and C',D' on the antennae are separated, respectively, 11 and 15 inches. All of the wires, including the antenna wires, are #6 copper-clad steel wire.

The wires leading from the points I, J to the transmitter are each approximately 1089 feet long; the said wires and, therefore, the two wires of each antenna, are fed in phase opposition.

The bearing of the horizontal line bisecting the angle between the wires AC and BD and the angle between the wires A'C' and B'D', taken from the open ends of the V's toward their apices, is approximately 282° East of true North.

Connected to the wires leading from the points I,J, to the transmitter, at points K and L 55.58 feet from I and J, are two parallel wires, KM and LN, each 8.42 feet long and spaced 12" apart, which wires KM and LN are open ended.

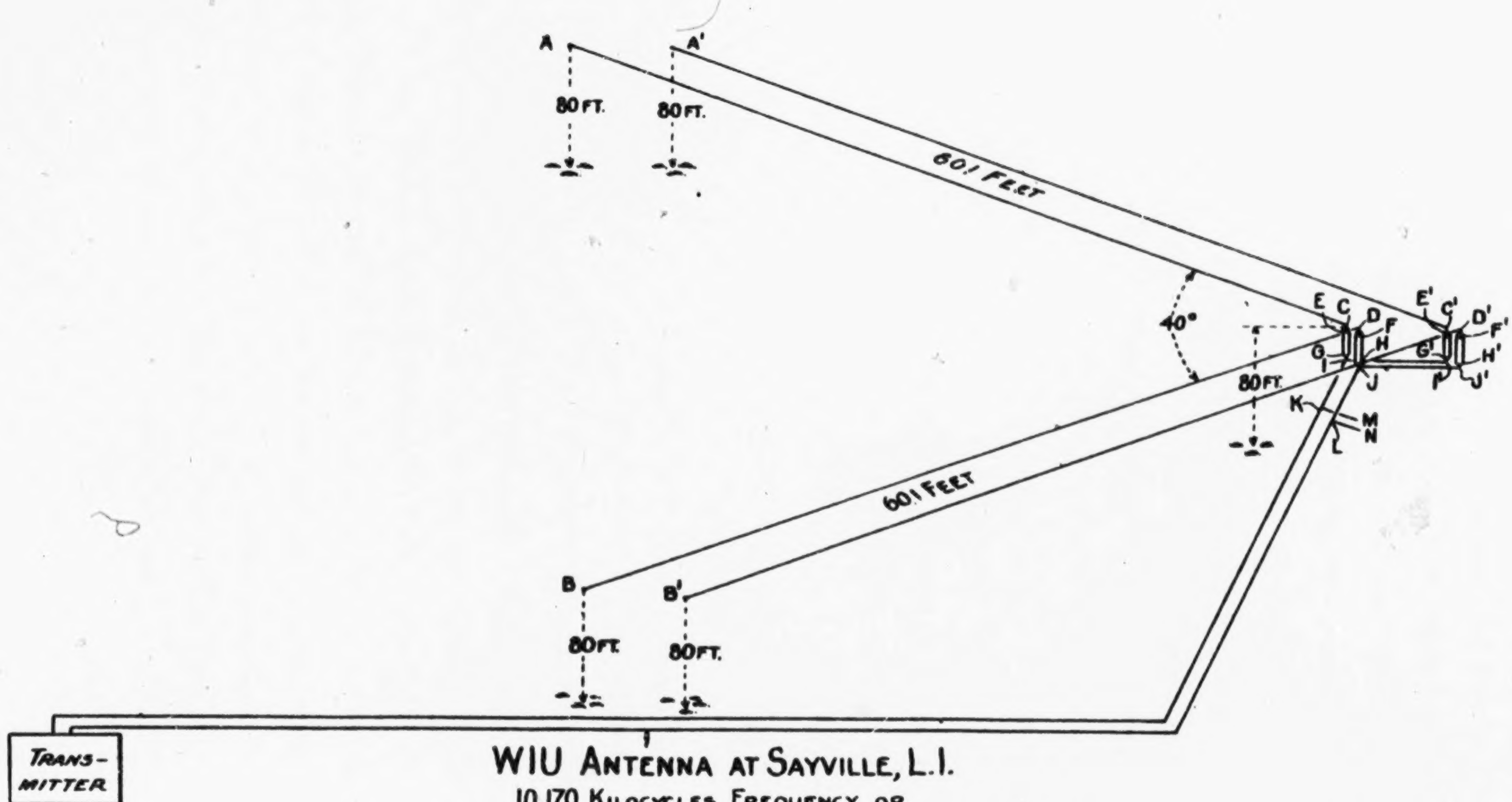
The antenna wires, together with the conductors leading from the transmitter to the antennae, the position and length of the pair of wires KM and LN, and the length, diameter and position of the copper tubes were so selected and adjusted, when the antenna system was installed, that an approximate impedance match was provided at each of the pairs of points

KL, GH and G'H', whereby energy is efficiently transferred across each of said pairs of points and reflection of waves toward the transmitter from each of said pairs of points is reduced. Waves are reflected intentionally between the points I, J, and M, N, via K, L, as well as from the antenna ends A, B, toward the points E, F, and from the antenna ends A',B', toward the points E', F'. The reflected waves are reduced as above stated on the wires GI, HJ, G'I'I, and H'J'J and on the wires leading from points K,L, to the transmitter. The antenna system is directive, and the angle between the wires AC and BD and between A'C' and B'D' is 40°.

The dimensional data set forth in the foregoing description, together with alternative statements of certain dimensions in terms of wave lengths, are tabulated in Exhibit G.

Antenna #9 was, at the time of the commencement of this suit, constructed and adjusted like No. 1, described in the foregoing, except as to the specific differences shown by the tabulation in Exhibit G.

EXHIBIT C-WIU ANTENNA SYSTEM
(ANTENNA No. 1)



WIU ANTENNA AT SAYVILLE, L.I.
10,170 KILOCYCLES FREQUENCY OR
WAVELENGTH - λ = 29.50 METERS (96.79 FEET)

PLAINTIFF'S EXHIBIT No. 10

DESCRIPTION OF SAYVILLE ANTENNA NO. 2

The defendant's WML antenna system at Sayville, Long Island, New York, had, at the time of the commencement of this suit, substantially the arrangement and dimensions shown in the drawing hereto annexed and marked "Exhibit D, WML Antenna System". This antenna system, at the time above stated, was being utilized by defendant in the transmission of commercial messages for pay to the European cities of Copenhagen (bearing approximately N 43° E), Vienna (bearing approximately N 50° E), Budapest (bearing approximately N 50° E), and Vatican City (bearing approximately N 58° E) on a wave-frequency of 14,740 kilocycles, which corresponds to a wavelength of 20.35 meters (66.77 feet). Following is a description of this antenna system as it existed at the time above stated (the reference characters being shown on the said diagram):

The radiating system comprises a single V-type antenna, ACBD, lying in a horizontal plane 80 feet above the ground surface. The length of each of the two antenna wires, AC and BD, is 517 feet. The adjacent ends, C, D, of the two wires constituting the V antenna are connected by vertical wires, each 67 feet long and spaced 12" apart, to the points I, J, and thence by a horizontal continuation of these wires, similarly spaced and each approximately 752 feet long, to the transmitter. The points C and D on the antenna are spaced 9" apart. All of the wires, including the antenna wires, are #6 copper-clad steel wire.

The said wires leading from the transmitter to the points C, D, and, therefore, the two wires of the antenna, are fed in phase opposition.

The bearing of the horizontal line bisecting the angle between the wires AC and BD, taken from the open ends toward the apex, is approximately 50° East of true North.

Connected to the wires leading from the points C,D to the transmitter, at points K and L 30 feet from I and J, are two parallel wires, KM and LN, each 7.17 feet long and spaced 12" apart. The wires KM and LN are closed by the cross-connection MN, located 7.17 feet from K, L.

The antenna wires, together with the wires from the transmitter to the antenna, the position and length of the pair of wires KM and LN, and the position of the cross-connection MN, were so adjusted, when the antenna system was installed, that an approximate impedance match was provided at the pair of points KL, whereby energy is efficiently transferred across each of said pairs of points and reflection of waves toward the transmitter from said pair of points is reduced. Waves are reflected intentionally between the antenna ends A,B, and the points MN, via KL. The antenna system is directive, and the angle between the wires AC and BD is 35°.

The dimensional data set forth in the foregoing description, together with alternative statements of certain dimensions in terms of wave lengths, are tabulated in Exhibit G.

Antenna #3 was, at the time of the commencement of this suit, constructed and adjusted like No. 2 described in

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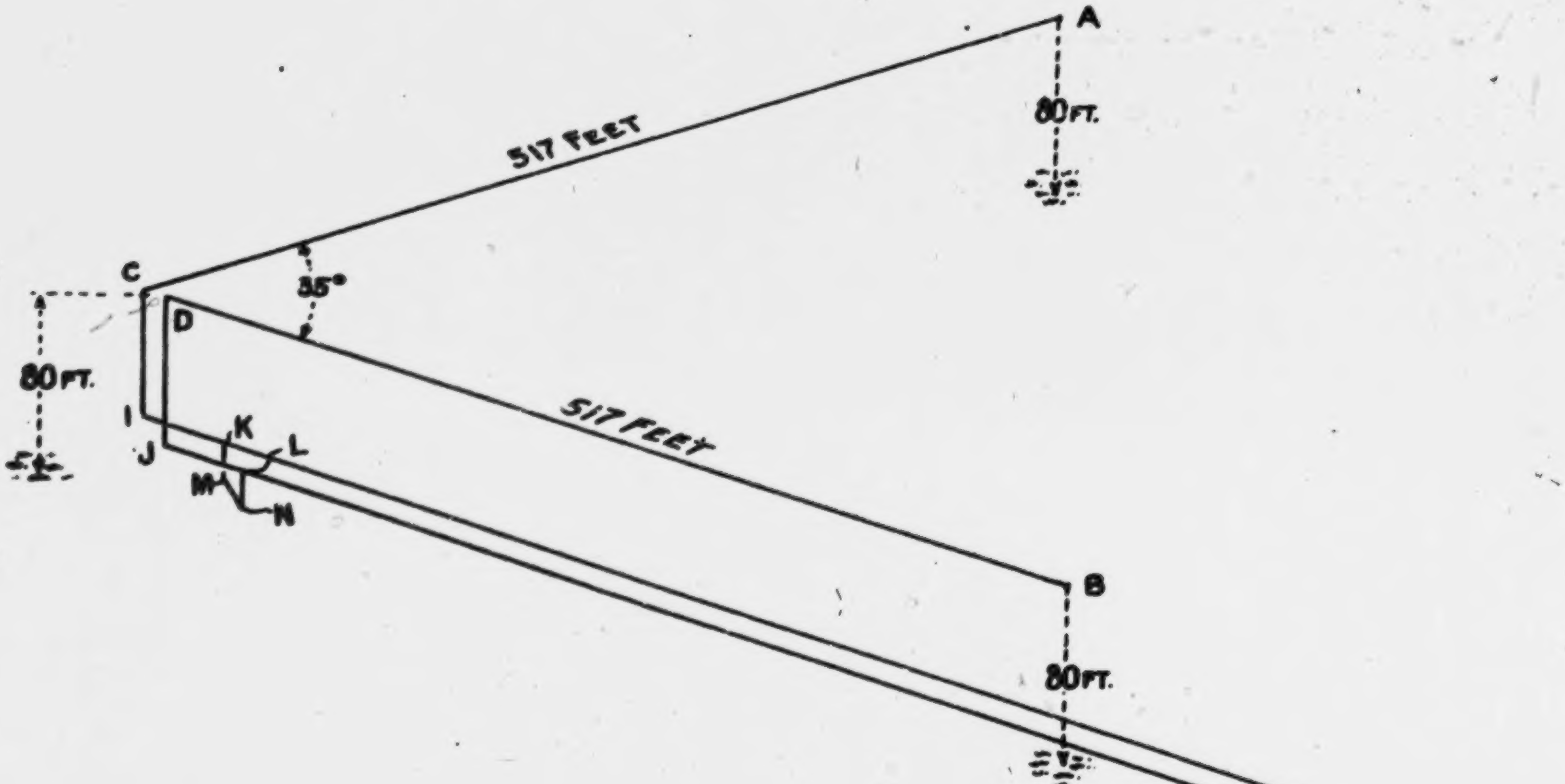
the foregoing, except as to specific differences which so far as now known are shown by the tabulation in Exhibit G.

Antennae Nos. 2 and 3 were rebuilt after the commencement of this suit, and when rebuilt were constructed and adjusted like antenna #2 above described, except as to the specific differences shown by the tabulation in Exhibit G.

(7-22-35)

10/3

Exhibit D-WML Antenna System
(Antenna No.2)



WML Antenna at Sayville, L.I.

14,740 Kilocycles Frequency or
Wavelength - λ - 20.35 meters (66.77 feet)

PLAINTIFF'S EXHIBIT No. 11

DESCRIPTION OF SAYVILLE ANTENNA #11

The defendant's WKS antenna system at Sayville, Long Island, New York, had, at the time of the commencement of this suit, substantially the arrangement and dimensions shown in the drawing hereto annexed and marked "Exhibit E, WKS Antenna System". This antenna system, at the time above stated, was being utilized by defendant in the transmission of commercial messages for pay to the European cities of Copenhagen (bearing approximately N 43° E), Vienna (bearing approximately N 50° E), Budapest (bearing approximately N 50° E), and Vatican City (bearing approximately N 58° E) on a wave-frequency of 16,285 kilocycles, which corresponds to a wavelength of 18.42 meters (60.44 feet). Following is a description of this antenna system as it existed at the time above stated (the reference characters being shown on the said diagram):

The radiating system comprises a single V-type antenna, ACBD, lying in a horizontal plane 80 feet above the ground surface. The length of each of the two antenna wires, AC and BD, is 465 feet. The adjacent ends, C, D, of the two wires constituting the V antenna are connected by wires, each 2.1 feet long, to the upper ends E, F, of two vertical copper tubes each 15.08 feet long, having an outside diameter of 13/16 of an inch, and spaced 6 inches apart, center to center; the lower ends G, H, of these tubes are connected by wires, 1.5 feet long, to the points I,J. The distance from the points C, D, to the points I, J, is 18.75 feet. Another pair of parallel wires, 12" apart and each approximately 111 feet long, leads from the points I,J, to the transmitter.

The points C and D on the antenna are spaced 9 inches apart. All of the wires, including the antenna wires, are #6 copper-clad steel wire.

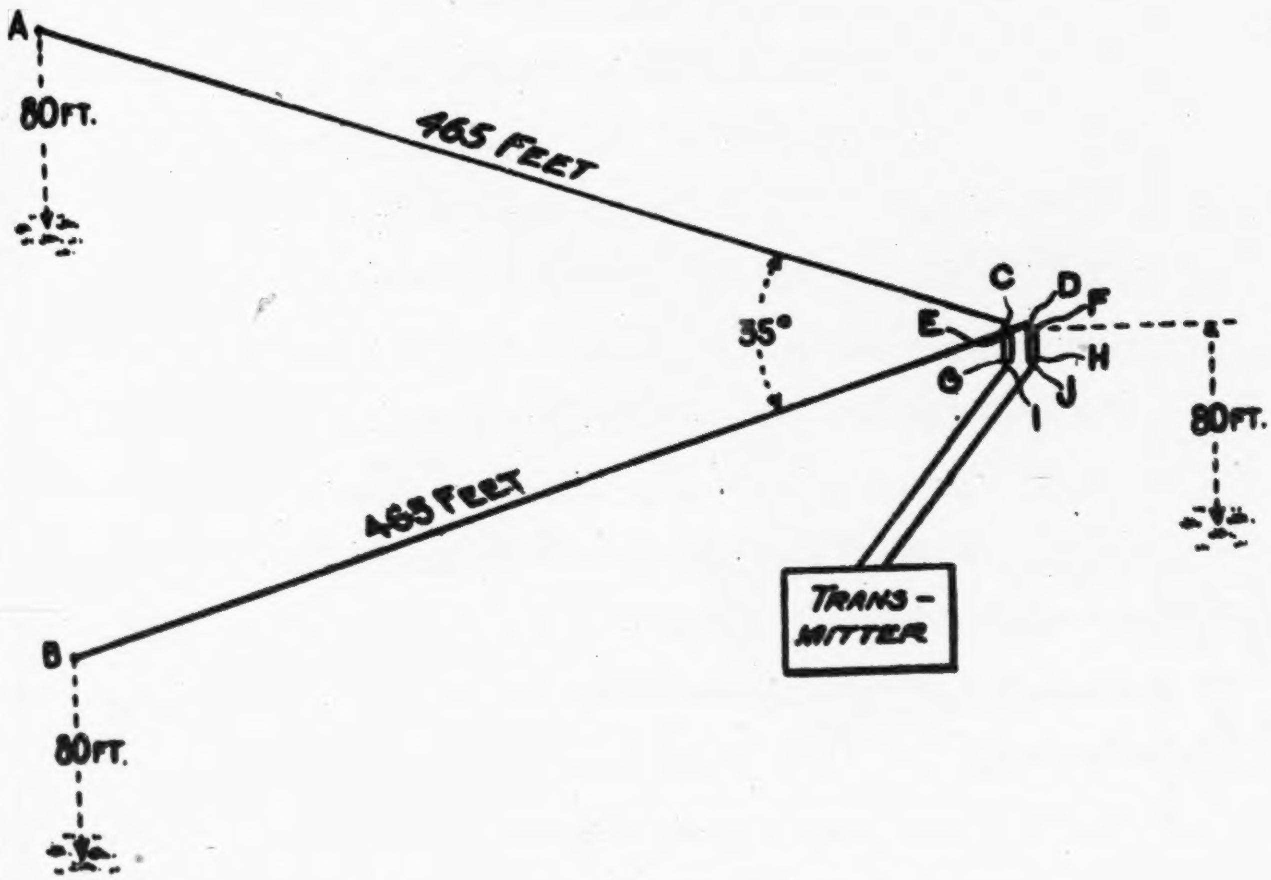
The said wires leading from the transmitter to the points C, D, and, therefore, the two wires of the antenna, are fed in phase opposition.

The bearing of the horizontal line bisecting the angle between the wires AC and BD, taken from the apex toward the open ends, is approximately 48° East of true North.

The antenna wires, together with the conductors from the transmitter to the antenna, and the length, diameter, and position of the copper tubes, were so selected and adjusted, when the antenna system was installed, that an approximate impedance match was provided at the pair of points GH, whereby energy is efficiently transferred across each of said pairs of points and reflection of waves toward the transmitter from said pair of points is reduced. Waves are reflected intentionally from the antenna ends A,B, toward the points EF. The antenna system is directive, and the angle between the wires AC and BD is 35°.

The dimensional data set forth in the foregoing description, together with alternative statements of certain dimensions in terms of wave lengths, are tabulated in Exhibit G.

Exhibit E–WKS Antenna System
(Antenna No. 11)



WKS Antenna at Sayville, L.I.

16,285 Kilocycles Frequency or

Wavelength = λ = 18.42 meters (60.44 feet)

PLAINTIFF'S EXHIBIT No. 12

DESCRIPTION OF SAYVILLE ANTENNA NO. 7

The defendant's WJE antenna system at Sayville, Long Island, New York, had, at the time of the commencement of this suit, substantially the arrangement and dimensions shown in the drawing hereto annexed and marked "Exhibit F, WJE Antenna System". This antenna system, at the time above stated, was being utilized by defendant in the transmission of commercial messages for pay to Buenos Aires (bearing approximately N 167° E), Camaguay (bearing approximately N 182° E), Seattle (bearing approximately N 298° E), and New Orleans (bearing approximately N 237° E), on a wave-frequency of 10,830 kilocycles, which corresponds to a wavelength of 27.7 meters (90.88 feet). Following is a description of this antenna system as it existed at the time above stated (the reference characters being shown on said diagram):

The antenna system comprises two V-type antennae (ACBD and A'C'B'D', respectively), lying in the same horizontal plane 80 feet above the ground surface. The length of each of the four antenna wires AC, BD, A'C', and B'D' is 567 feet. The adjacent ends, C, D, of the two wires constituting one V antenna are connected by wires, each 45 feet long, to the upper ends E, F, of two vertical copper tubes each 22.76 feet long, having an outside diameter of one inch, and spaced 7 inches apart, center to center; the lower ends G, H, of these tubes are connected direct to the junction points I, J. The distance from the points C, D, to the points, I, J, is 67.75 feet. Another pair of parallel

wires 12" apart leads from the points I, J, to the transmitter. The adjacent ends C',D' of the wires constituting the other V antenna are connected by wires, each 45 feet long, to the upper ends E',F', of two vertical copper tubes each 22.76 feet long, having an outside diameter of one inch, and spaced 7 inches apart, center to center; the lower ends G',H', of these tubes are connected direct to the points I',J', and thence by horizontal wires, spaced 12" apart and each 68.33 feet long, to the junction points I, J. The distance from the points C',D', to the points I',J', is 67.75 feet. Each of the points C, D and C',D' on the antennae are separated 10 inches. All of the wires, including the antenna wires, are #6 copper-clad steel wire.

The wires leading from the points I,J to the transmitter are each approximately 151 feet long; the said wires and, therefore, the two wires of each antenna, are fed in phase opposition.

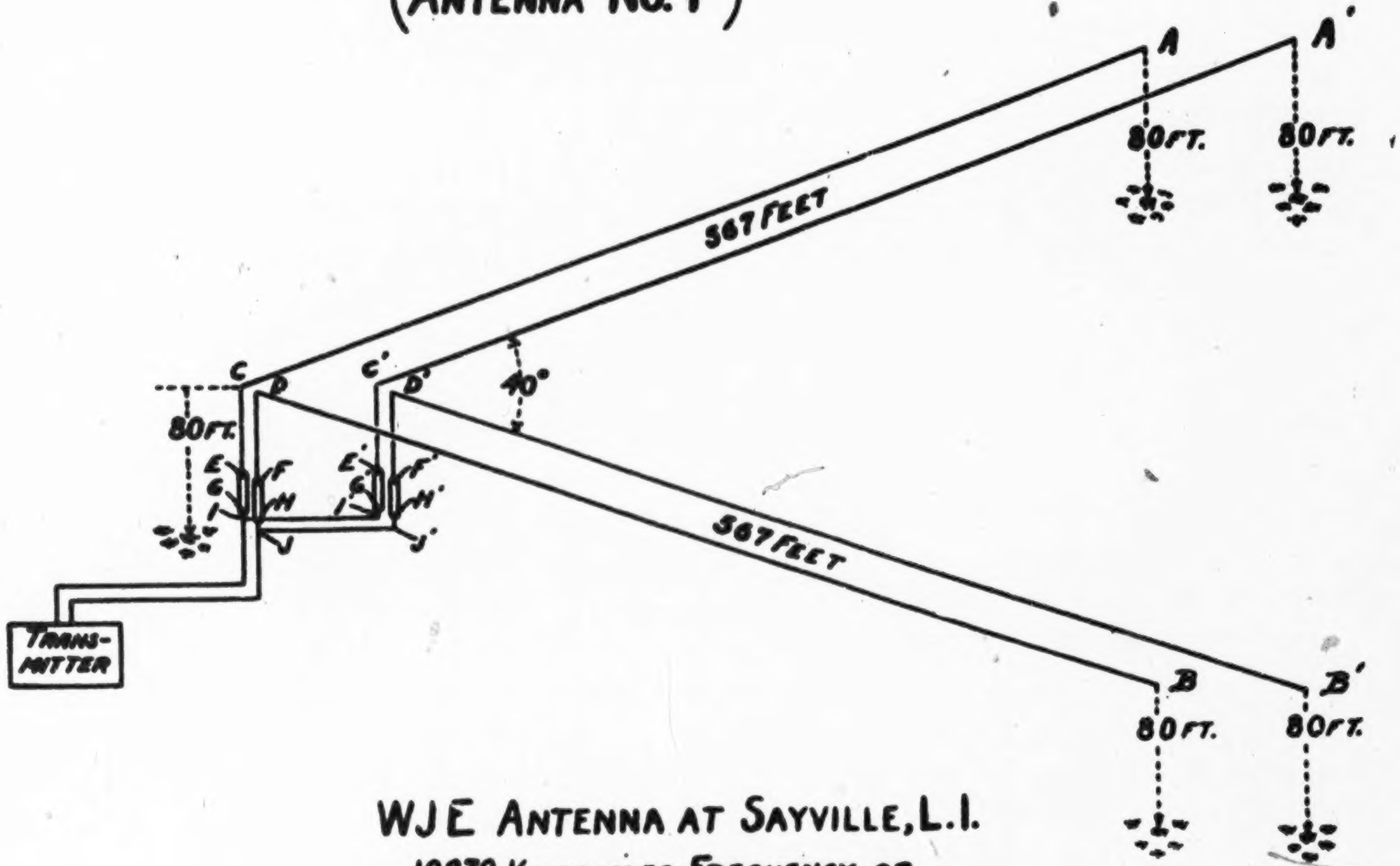
The bearing of the horizontal line bisecting the angle between the wires AC and BD and the angle between the wires A'C' and B'D', taken from the apices toward the open ends of the V's, is approximately 167° East of true North.

The antenna wires, together with the conductors leading from the transmitter to the antennae, and the length, diameter, and position of the copper tubes were so selected and adjusted, when the antenna system was installed, that an approximate impedance match was provided at each of the pairs

of points GH and G'H', whereby energy is efficiently transferred across each of said pairs of points and reflection of waves toward the transmitter from G'H' is reduced. Waves are reflected intentionally from the antenna ends A,B, toward the points E,F, and from the antenna ends A',B', toward the points E',F'. The reflected waves are reduced as above stated on the wires G'I'I, and H'J'J. The antenna system is directive, and the angle between the wires AC and BD and between A'C' and B'D' is 40°.

The dimensional data set forth in the foregoing description, together with alternative statements of certain dimensions in terms of wave lengths, are tabulated in Exhibit 6.

Exhibit F - WJE Antenna System
(Antenna No. 7)



WJE Antenna at Sayville, L.I.
10830 Kilocycles Frequency or
Wavelength $= \lambda =$ 27.7 meters (90.88 feet)

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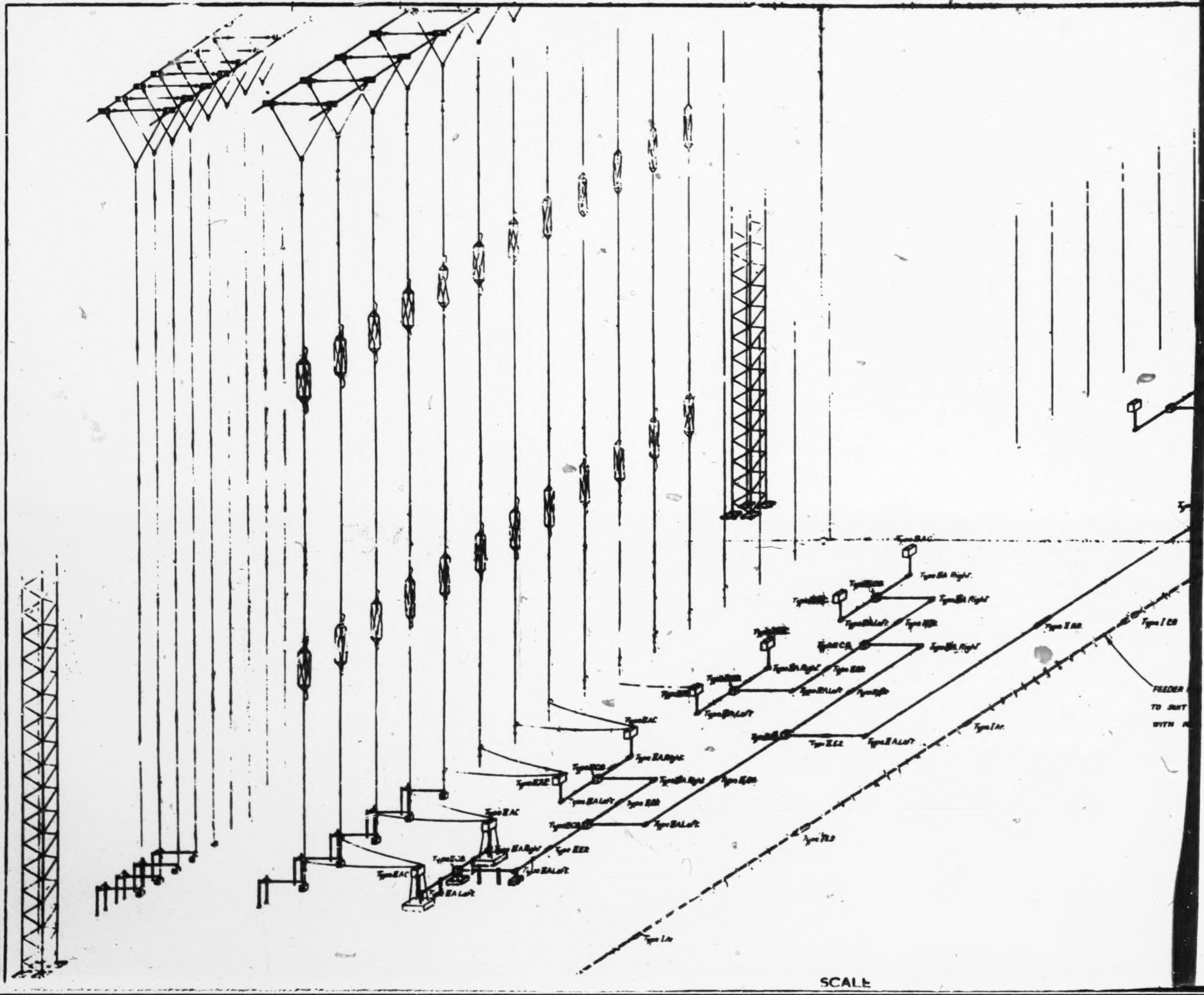
EXHIBIT G ~ Tabulation of Dimensional Data for V-Antennas at Sayville

Sheet I

Antenna No.	1	2 Original	2 Rebuilt	3 Original	3 Rebuilt	4	5	6	7	8	9	10	11
Call Letters	WIU	WML	WKB	WKR	WIX	WJH	WIW	WMY	WJE	WMZ	WKI	WKT	WKS
Frequency	10170 Kc	14740 Kc	14695 Kc	17140 KC	10820 KC	13018 KC.	10810 KC	20980 KC	10830 KC	5990 KC	14710 KC	16370 KC	16285 KC
Wavelength	29.50m.	20.35 m.	20.42 m.	17.50 m.	27.73 m	23.05 m	27.75 m	14.30 m	27.70 m	50.08 m	20.39 m.	18.326 m.	18.42 m.
Wavelength	96.79 ft	66.77 ft.	66.99 ft.	57.43 ft	90.98 ft.	75.63 ft	91.04 ft	46.92 ft.	90.88 ft	164.3 ft.	66.90 ft.	60.13 ft.	60.44 ft
Single or Double V	Double	Single	Single	Single	Single	Double	Double	Double	Double	Double	Double	Double	Single
Communicates with (Gnd bearing E. of N.)	San Francisco (281.28°)	Copenhagen (43.36°) Vienna (49.74°) Budapest (40.62°) Vatican City (57.9°)	San Francisco (281.28°)	Budapest (49.62°)	New Orleans (236.59°)	Copenhagen (43.36°) Vienna (40.74°) Budapest (49.62°) Vatican City (57.9°)	Copenhagen (43.36°) Vienna (49.74°) Budapest (49.62°) Vatican City (57.9°)	Buenos Aires (167.44°)	Buenos Aires (167.44°) Camaguey (182.47°) Seattle (297.58°) New Orleans (236.59°)	San Francisco (281.28°) Chicago (278.46°)	San Francisco (281.28°)	San Francisco (281.28°)	Copenhagen (43.36°) Vienna (49.74°) Budapest (49.62°) Vatican City (57.9°)
Directivity E. of N.	281.95°	40.75°	280.92°	49.62°	238°	48.25°	48.25°	167.5°	167.5°	281.95°	281.95°	281.95°	48.25°
Length of Trans-mission	1089 ft	752 ft.	478 ft.	Unknown	1265 ft	516 ft.	837 ft	600 ft	151 ft.	800 ft.	624 ft.	221 ft.	111 ft.
Angle of V Apex	40°	35°	40°	35.73°	43°	35°	40°	35°	40°	45°	35°	35°	35°
Length One V Wire	6.21 wl.	7.74 wl.	8.14 wl.	7.69 wl.	4.85 wl.	7.69 wl.	6.21 wl.	7.07 wl.	6.24 wl.	4. wl.	7.70 wl.	7.17 wl.	7.69 wl.
do.	601 ft.	517 ft	545 ft	441.5 ft	441.5 ft	582 ft	565 ft.	360 ft.	567 ft.	657 ft.	515 ft.	431 ft.	465 ft.
Height above ground	0.83 wl.	1.2 wl	1.19 wl.	1.39 wl	0.88 wl.	1.06 wl.	0.9 wl.	1.49 wl.	0.88 wl.	0.49 wl.	1.2 wl.	1.33 wl.	1.32 wl.
do.	80 ft.	80 ft.	80 ft	80 ft	80 ft.	80 ft.	80 ft	70 ft.	80 ft.	80 ft.	80 ft.	80 ft	80 ft.
Separation of V's	3/4 wl.	—	—	—	—	1 1/4 wl.	3/4 wl.	1 3/4 wl.	3/4 wl.	3/4 wl.	1 3/4 wl.	2 1/4 wl.	—
do.	72.67 ft.	—	—	—	—	94.67 ft.	68.25 ft.	82 ft.	68.33 ft.	123 ft.	117 ft.	135 ft.	—

EXHIBIT G Tabulation of Dimensional Data for V-Antennas at Sayville, con. Sheet II

Antenna No.:	1	2 Original	2 Rebuilt	3 Original	3 Rebuilt	4	5	6	7	8	9	10	11
Length C to I, D to J	26.33 ft.	67 ft	43.83 ft	Unknown	5.42 ft.	20.42 ft	25.25 ft	15.42 ft.	67.75 ft	42 ft	19.83 ft	16.58 ft.	18.75 ft.
Length C' to I', D' to J'	26.33 ft	—	—	—	—	20.58 ft.	25.23 ft.	14.42 ft.	67.75 ft	42 ft.	19.5 ft.	16.58 ft.	—
Length C to E, D to F	1.58 ft	—	—	—	—	1.5 ft.	2.5 ft.	2.25 ft.	45 ft.	—	2.67 ft.	1.58 ft.	2.1 ft.
Length C' to E', D' to F'	2.08 ft	—	—	—	—	1.67 ft	2.5 ft.	2.67 ft	45 ft.	—	2.75 ft.	1.58 ft.	—
Length E to G, F to H	24.2 ft.	—	—	—	—	18.81 ft.	22.72 ft	11.73 ft	22.76 ft	—	16.72 ft.	15.03 ft	15.08 ft
Length E' to G', F' to H'	24.2 ft	—	—	—	—	18.81 ft	22.72 ft	11.73 ft	22.76 ft	—	16.72 ft	15.03 ft	—
Length G to I, H to J	7 in	—	—	—	—	0	0	1.42 ft	0	—	5 in.	0	1.5 ft.
Length G' to I', H' to J'	0	—	—	—	—	0	0	0	0	—	0	0	—
O.D. Copper Tubes	1 in.	—	—	—	—	1 in.	1 in.	1 in.	1 in.	—	1 in.	1 in.	13/16 in.
Spacing of EG-FH (C to G)	7.5 in.	—	—	—	—	6 in.	7.5 in.	4.25 in.	7 in.	—	8 in.	9.5 in.	6 in.
Spacing of E'G'-F'H' (C' to G')	5.5 in	—	—	—	—	6.5 in	7 in	5 in	7 in.	—	8.5 in.	7.25 in.	—
Length I to K, J to L	55.58 ft	30 ft.	101.08 ft.	Unknown	107.33 ft.	80.25 ft.	51.08 ft.	72.58 ft.	—	12 ft.	108 ft.	4.5 ft.	—
Length K to M, L to N	8.42 ft	7.17 ft	8.33 ft.	Unknown	10.25 ft.	5.58 ft.	8.25 ft.	4.25 ft.	—	15 ft.	7.42 ft.	5.3 ft.	—
M-N open or closed	Open	Closed	Open	Unknown	Closed	Open	Open	Open	—	Open	Open	Open	—
Spacing C to D	11 in.	9 in.	9 in.	Unknown	12 in.	13 in.	10 in.	14 in.	10 in.	15 in.	10 in.	12 in.	9 in.
Spacing C' to D'	15 in.	—	—	—	—	12 in.	10 in.	10 in.	10 in.	15 in.	16 in.	10 in.	—
Length C to E, D to F	—	—	—	—	—	—	—	—	—	27 ft.	—	—	—
Length E to G, F to H	—	—	—	—	—	—	—	—	—	10 ft.	—	—	—
G-H open or closed	—	—	—	—	—	—	—	—	—	closed	—	—	—
Length C' to E', D' to F'	—	—	—	—	—	—	—	—	—	25 ft.	—	—	—
Length E' to G', F' to H'	—	—	—	—	—	—	—	—	—	9 ft.	—	—	—
G'-H' open or closed	—	—	—	—	—	—	—	—	—	closed	—	—	—



SCALE

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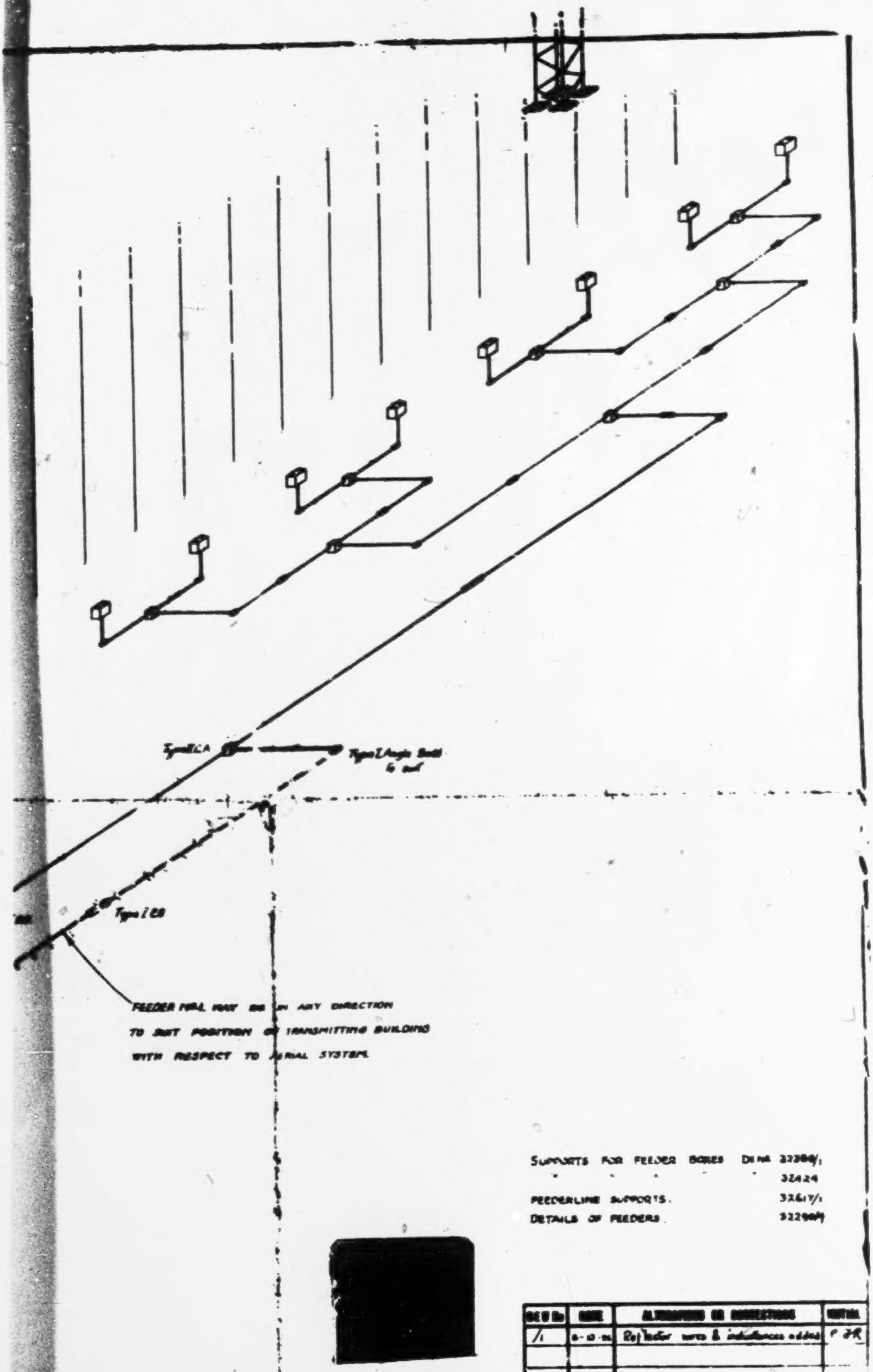

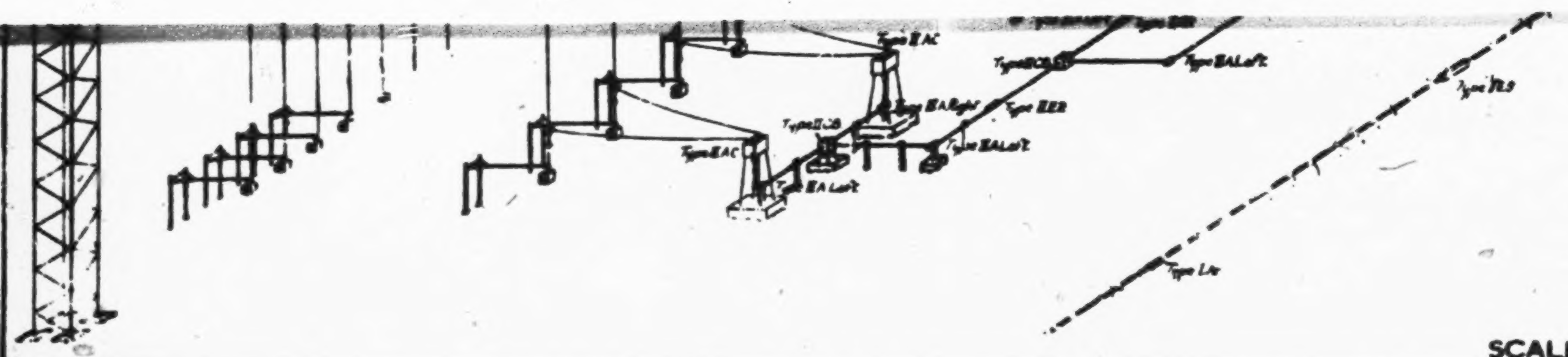

SCALE

BEAM STATIONS	SCHEMATIC DIAGRAM OF FEEDER CIRCUIT & AERIAL. FOR WAVERANCE 22·5 – 40 METRES.

WITH RESPECT TO AERIAL SYSTEM.

[redacted]

SUPPORTS FOR FEEDER BOXES DWG 32386/1
" " " " " 32424
FEEDERLINE SUPPORTS. 32617/1
DETAILS OF FEEDERS. 32290/1

REV No	DATE	ALTERATIONS OR CORRECTIONS	INITIAL
/1	8-10-36	Reflector wires & inductances added	PJR

DRAWN BY		MARCONI'S WIRELESS TELEGRAPH Cº LTD LONDON.
C.K.		
TRACED BY		
G.R.		
CHECKED BY		Nº 32251/1

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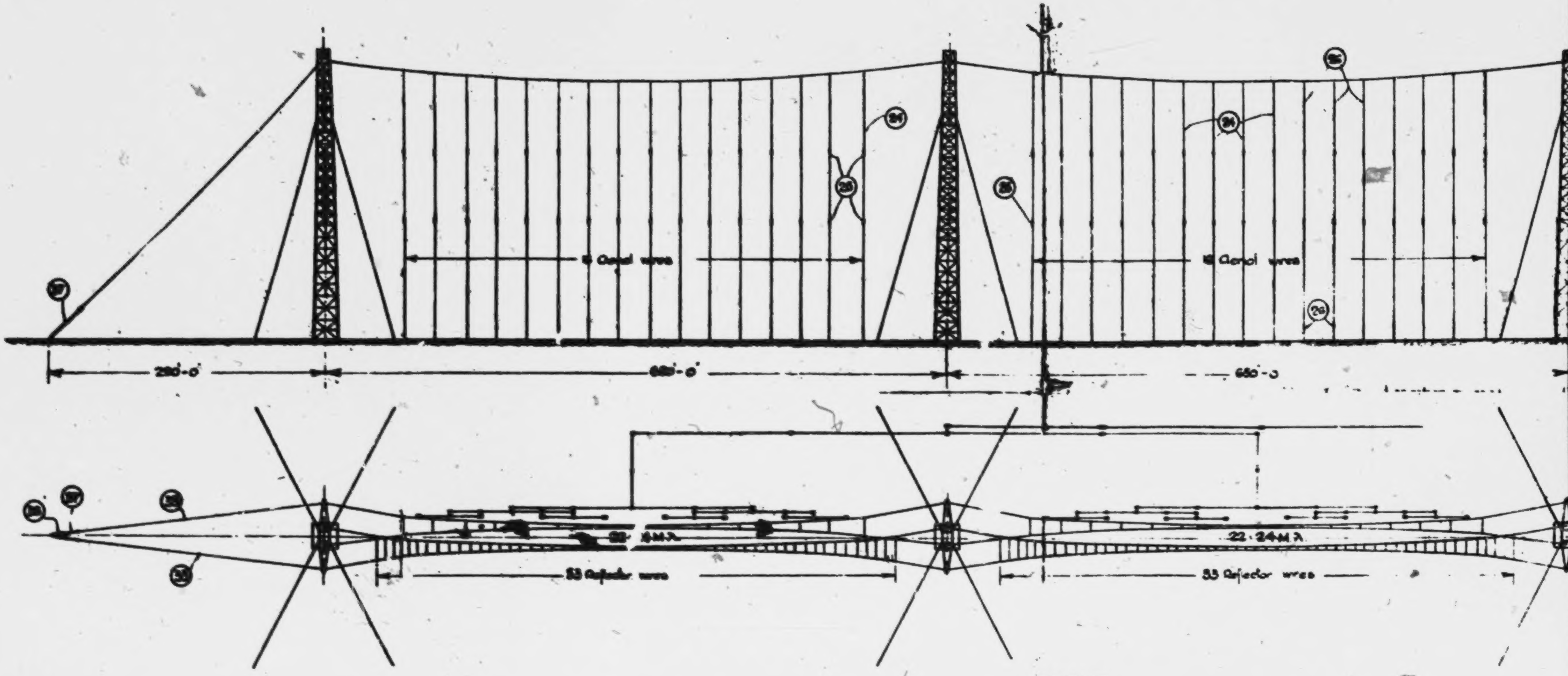
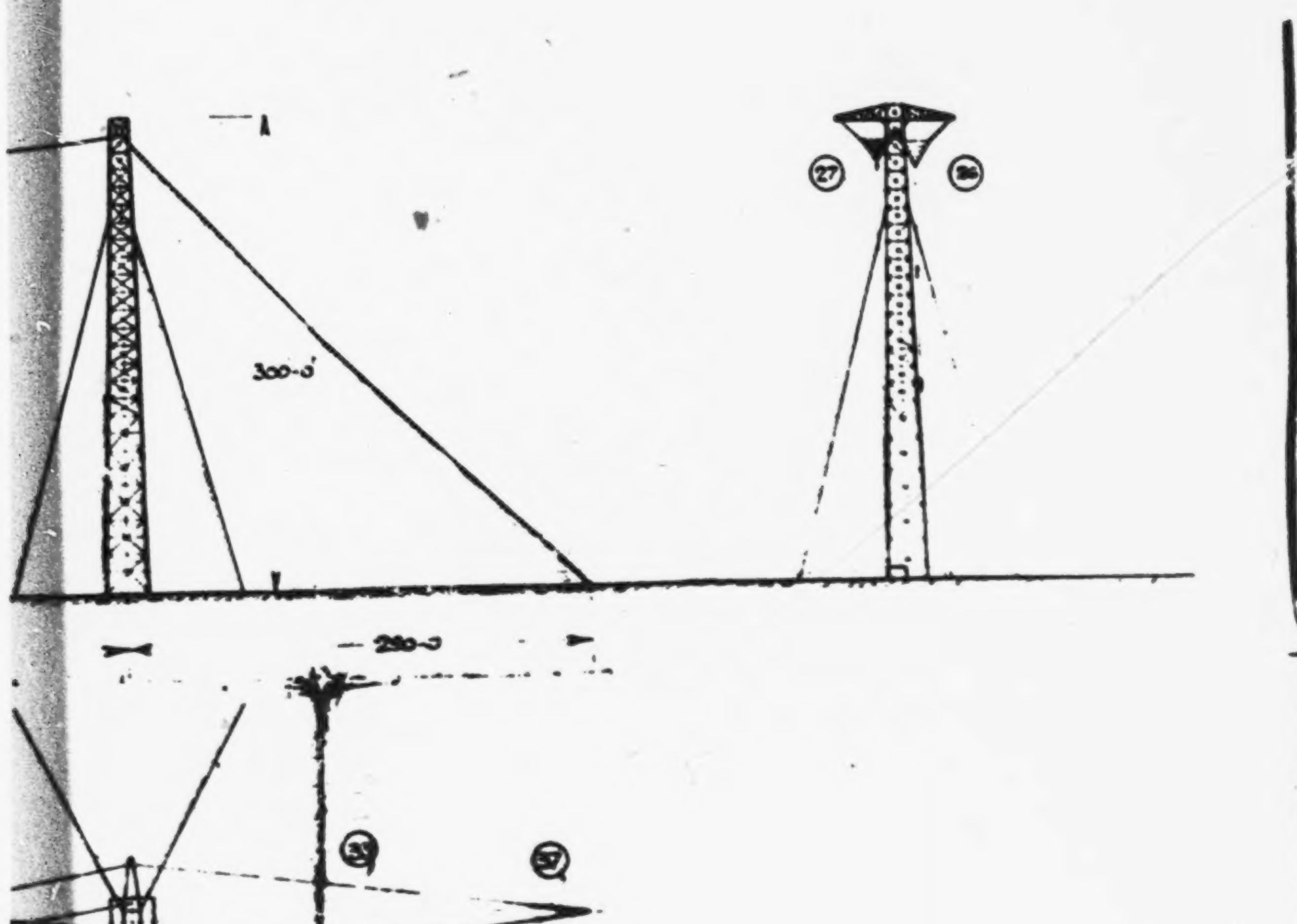


ROCKY POINT NEW YORK	GENERAL ARRANGEMENT OF AERIAL & REFLECTOR SYSTEM BEAM TRANSMITTER

720

PLAINTIFF'S EXHIBIT No. 15

No. 15



YSTEM

MARCONI'S WIRELESS TELEGRAPH Co LTD LONDON.

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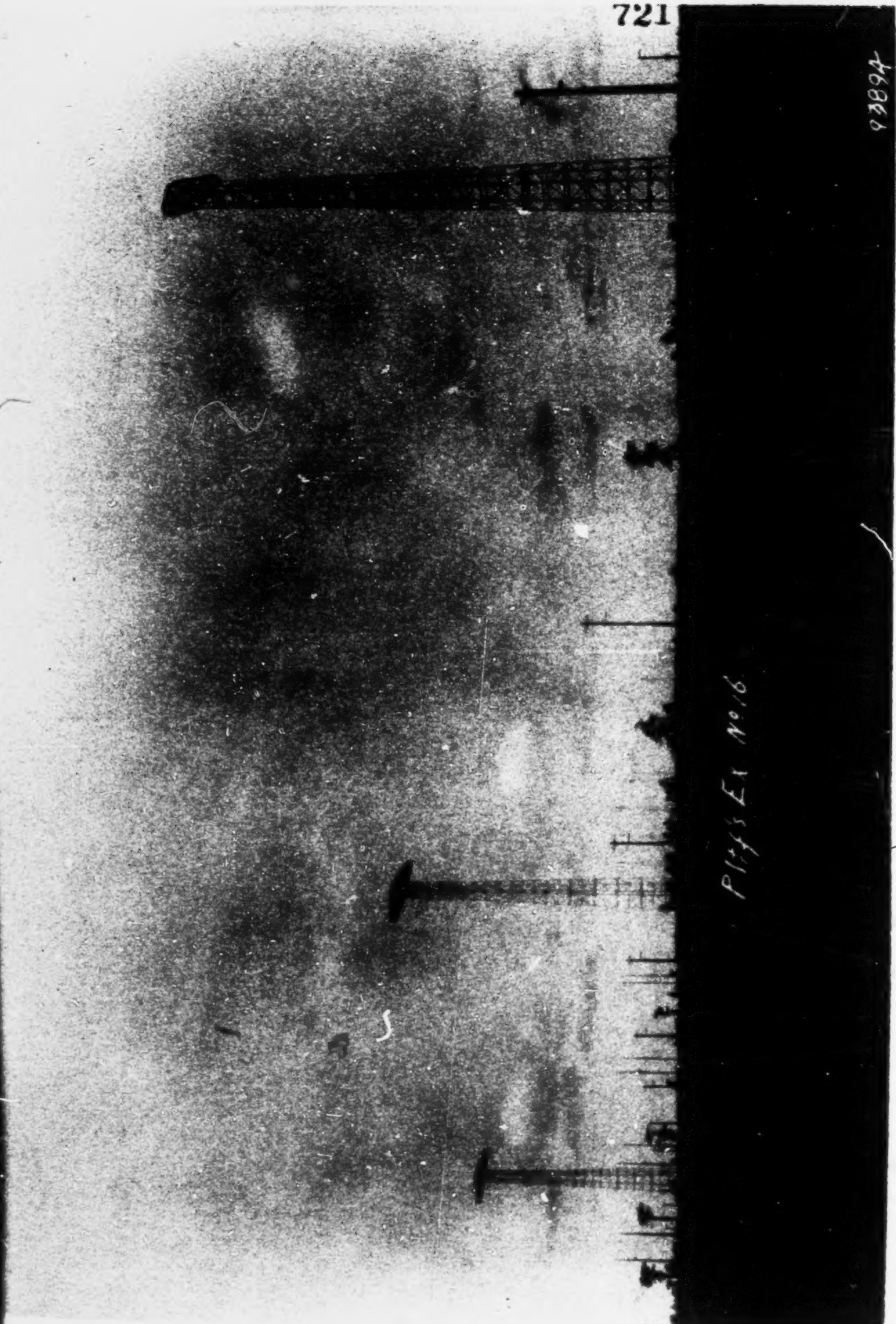

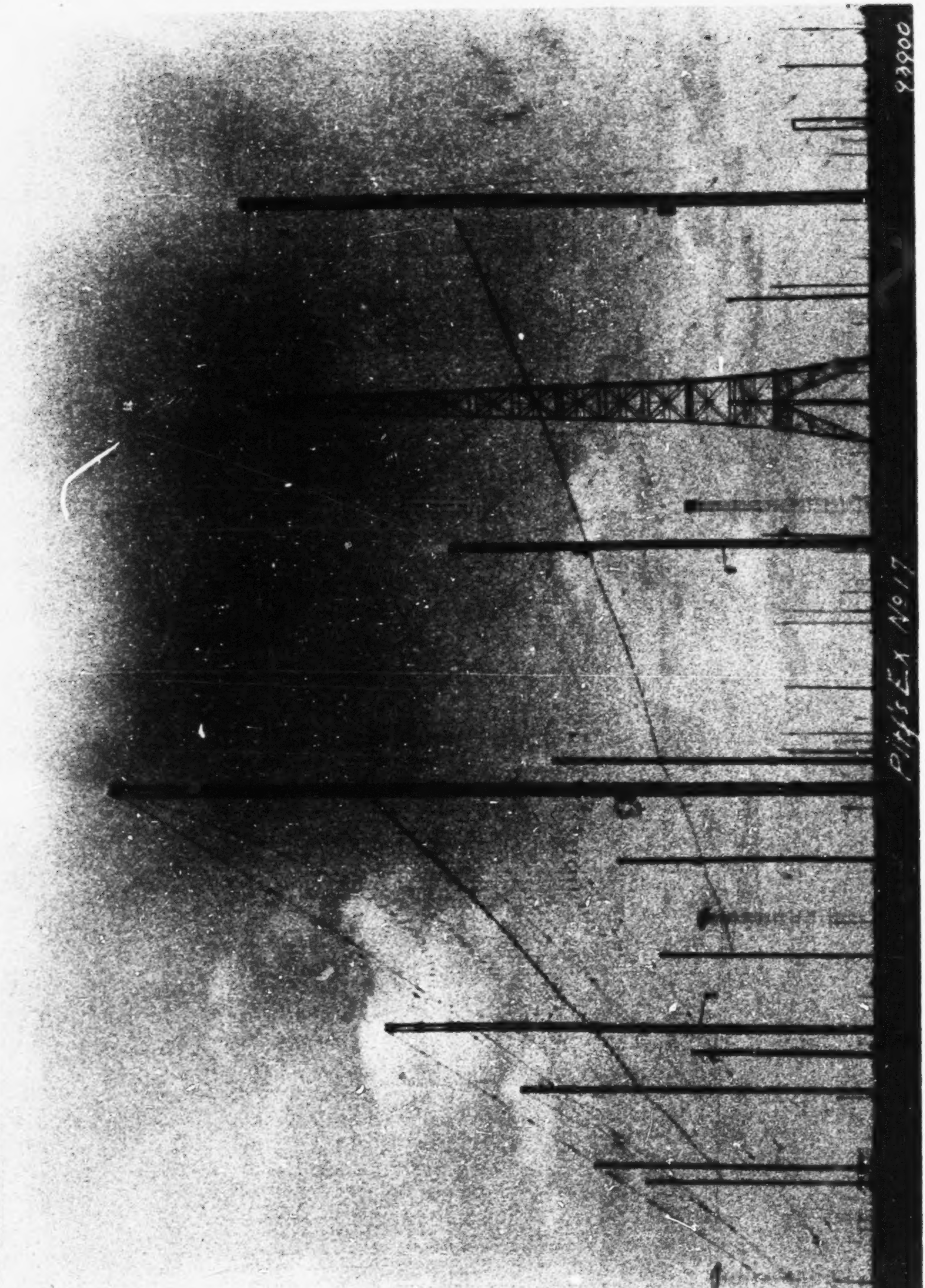
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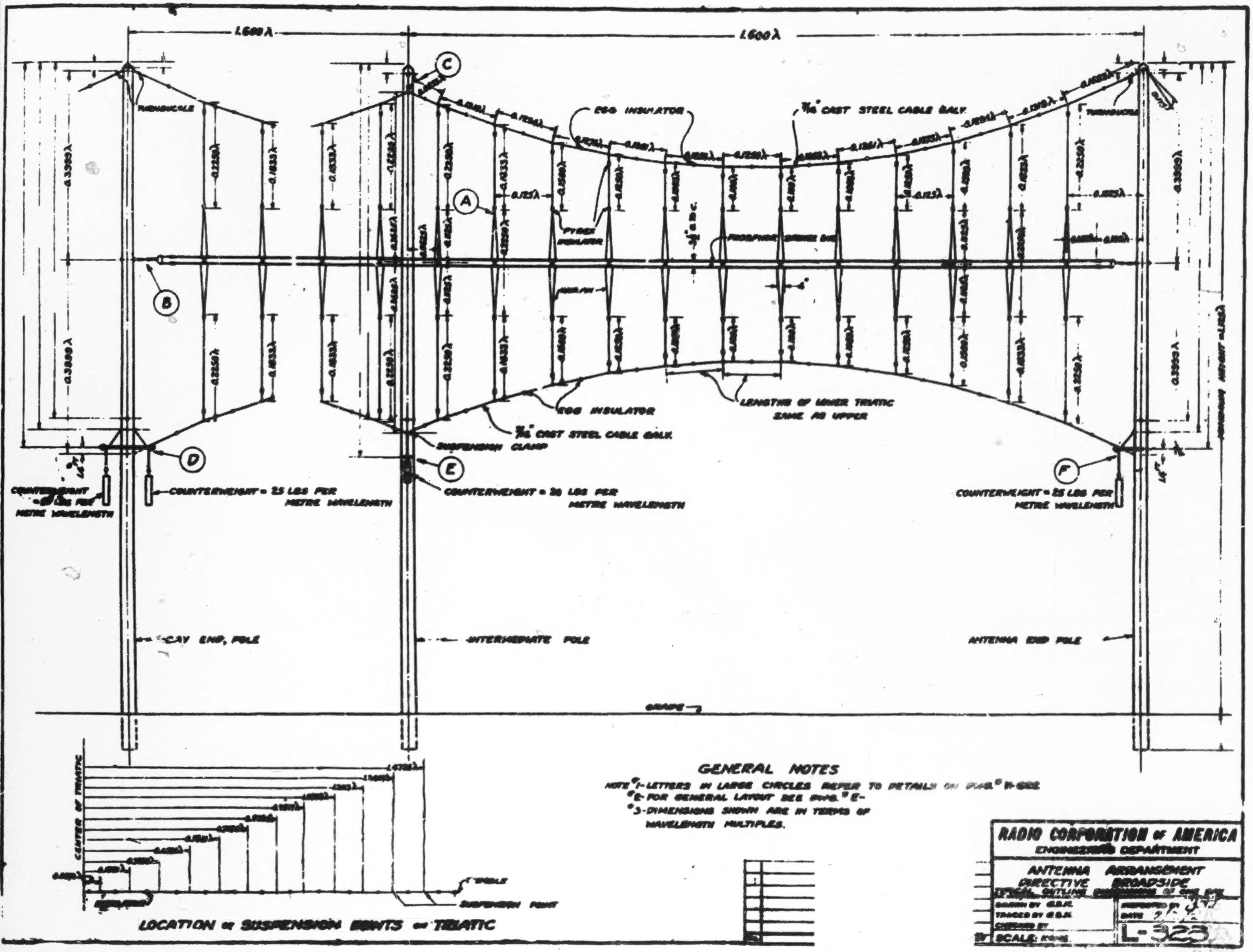
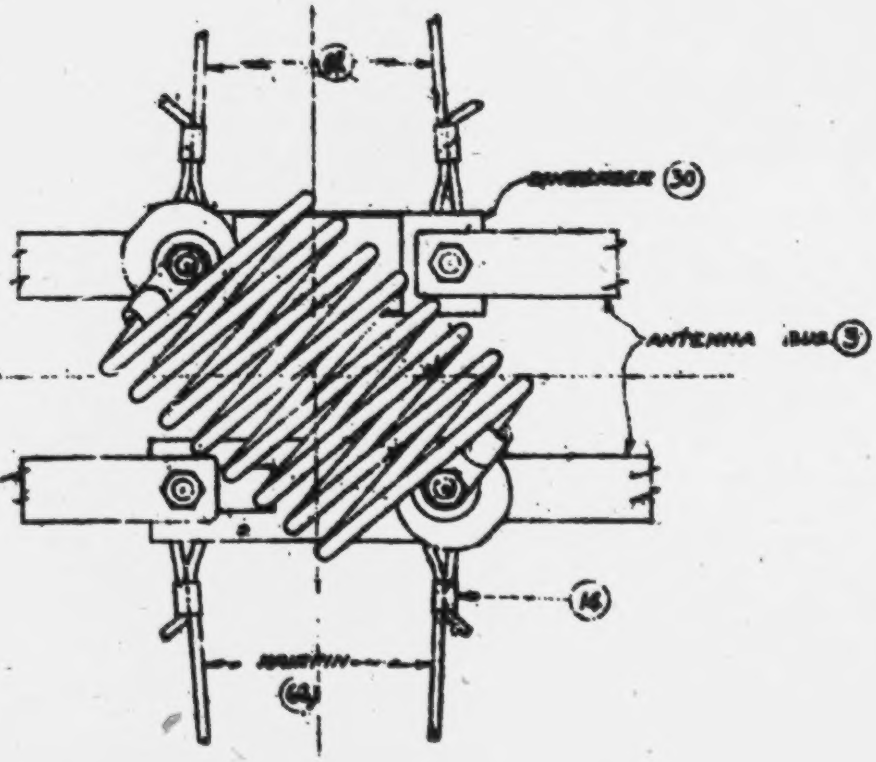
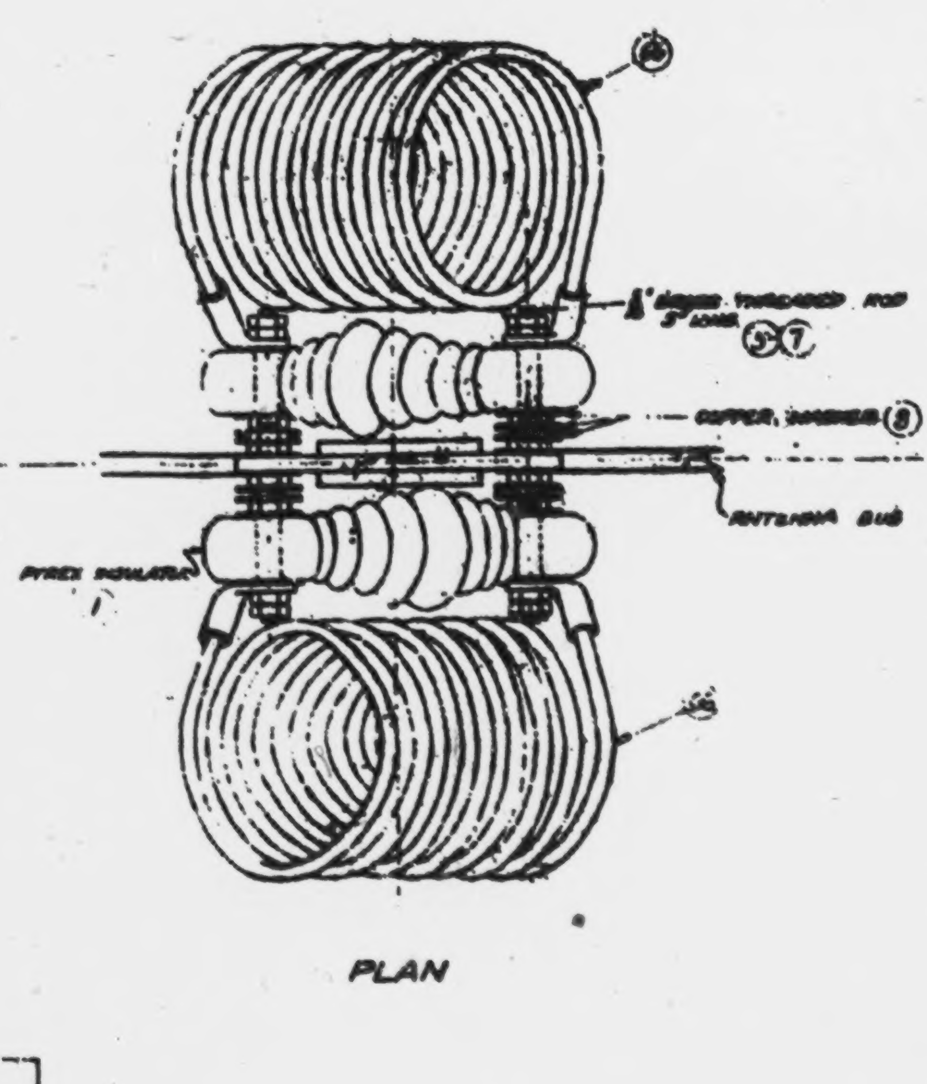




ELEVATION



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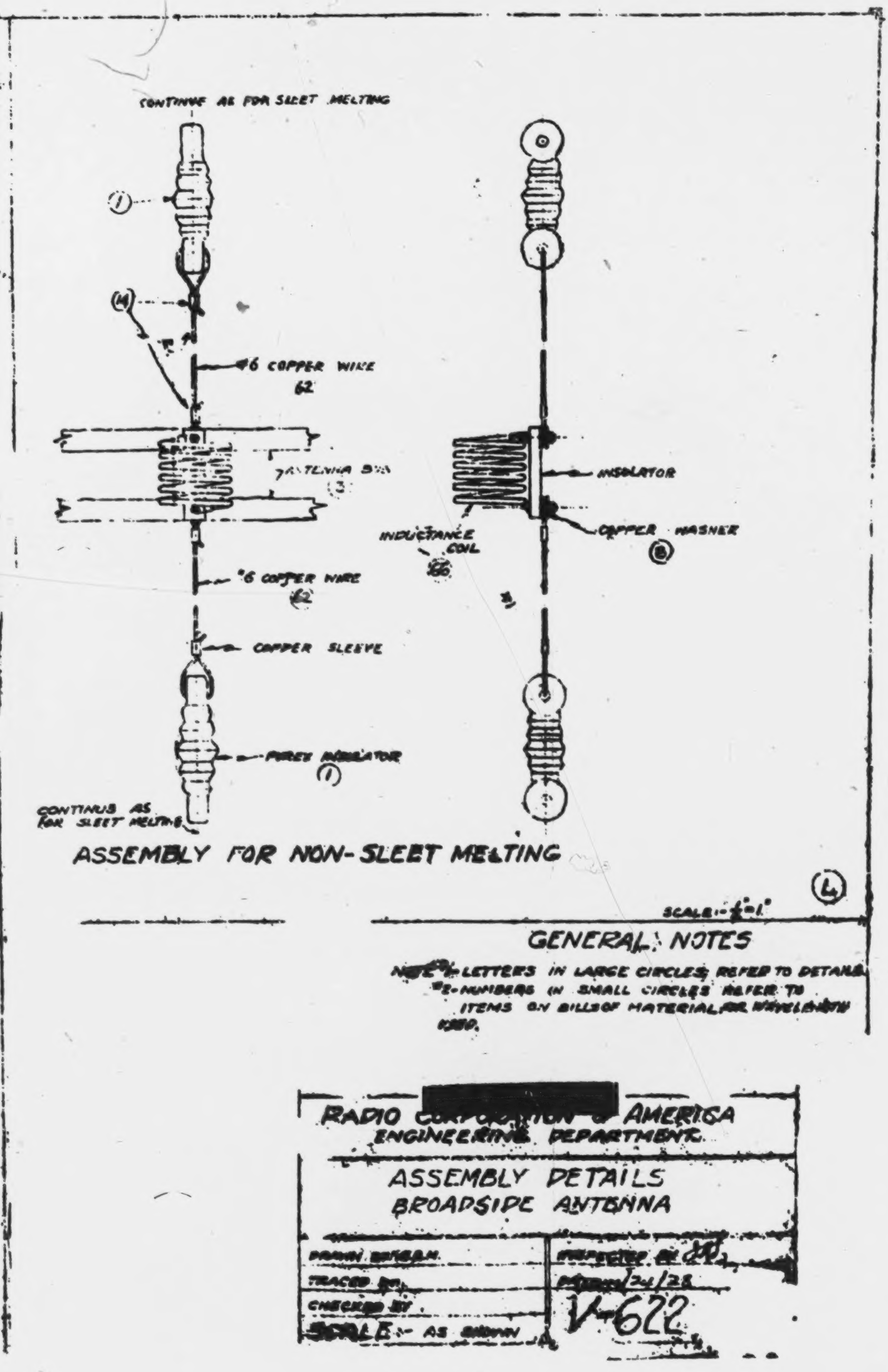

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DEVELOPMENT OF DIRECTIVE TRANSMITTING ANTENNAS BY R.C.A COMMUNICATIONS, INC.*

By
P. S. CARTER, C. W. HANSELL, AND N. E. LINDENBLAD
(R.C.A. Communications, Inc., Rocky Point, N. Y.)

Summary—*Progressive stages in the development of short-wave directive antennas for long-distance communication are outlined. The scope of development described embraces the period from 1923, beginning with experiments on a transmitting wave antenna at Belfast, Maine, to the present commercial directive antennas used in the world-wide short-wave system of R.C.A. Communications, Inc.*

Various types of directive antennas are theoretically analyzed and their performances under practical conditions studied. The effects of seasonal variations, heights above ground and polarization are considered. The radiation properties of simple wires and the radiation patterns of various combinations of wires are described in detail.

The economic aspects of these directive antennas as exemplified by the standard antenna models A, B, C, and D are developed.

INTRODUCTION

ACTIVE work on the development of directive transmitting antennas was begun by the engineers of the Radio Corporation of America[1] in 1923, at which time it was becoming apparent that wavelengths[2] of less than 200 meters might have important applications in radio communications. The application of these short wavelengths made it possible to deliver given amounts of signal power to distant receiving stations more economically by using directive antennas.

In setting out to develop directive transmitting antennas we had an ideal in performance to strive for represented by the wave antenna developed for long-wave reception by Beverage, Rice, and Kellogg.[3] This antenna, in addition to being very directional, is simple in structure and is substantially aperiodic. A single structure may be used for operation over a wide range of wavelength without any tuning adjustments.

EARLY WAVE ANTENNA EXPERIMENTS

Due to realization of the great advantages of the wave antenna for reception it was natural to choose it for the first directive transmitting

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[1] The group of engineers whose work is related in this paper are now in R.C.A. Communications, Inc., a subsidiary of the Radio Corporation of America, under C. H. Taylor, vice president, engineering.

[2] Wavelengths are used in this paper instead of frequency because of the close relation between wavelength and the factors affecting the design and explanation of directive antennas.

[3] "The Wave Antenna" by Beverage, Rice, and Kellogg, *Trans. A.I.E.E.*, 42, 258 et. seq., March, April, and May, 1923.

antenna experiments. On September 16, 1923, Beverage, Dean, and Hansell at Belfast, Maine, transmitted alternately with a plain antenna and a wave antenna while Peterson at Riverhead, Long Island, measured the strength of received signal.

The wave antenna used in these tests was three wavelengths long and was terminated at the distant end in a resistance equal to the characteristic impedance. A wavelength of 1650 meters was used.

Considering the current flowing in the input end of the wave antenna the apparent effective height, as determined by the signal measured at Riverhead, was more than twenty times the actual height of the antenna wires. This indicated considerable directivity.

The signal from the wave antenna was only about a quarter of that from the plain antenna, for approximately equal power, indicating low radiation efficiency. Still this first result seemed promising and a considerable amount of time was spent by Hansell, during the first half of 1924, at Belfast in studying the wave antenna for transmission.

The observations and conclusions made during this period will be briefly summarised as follows:

(1) The wave antenna gives a simple structure with considerable directivity both horizontally and vertically. The beam from it is inclined upward at an angle to the earth. A single structure may be used over a wide range of wavelengths without tuning adjustments.

(2) Except for end effect the useful radiation from the wave antenna, when used for transmitting, takes place only due to wave tilt produced by losses and low velocity of that portion of the field around the wires which enters the earth. Reducing the resistance and radiation losses in the earth also reduces the useful radiation so that high radiation efficiency does not result.

(3) To obtain efficient radiation without waste of energy in the ground it is necessary to employ an antenna structure which will itself produce a wave tilt. Such a structure is one in which the conductors carrying the waves have attached to them a series of radiators at right angles. These radiators then carry currents at right angles to the direction of the wave motion on the antenna and radiation takes place.

(4) In a receiving wave antenna the space waves can build up a continually increasing energy in the antenna as they sweep over it because they have a higher velocity than the antenna waves and so continually advance in phase relative to the antenna waves. Thus the counter electromotive force of the waves on the antenna cannot prevent the transfer of energy, because of its lagging phase.

When the same antenna is used for transmitting the conditions are reversed so that as soon as energy is transferred to the space waves it

advances in phase relative to the waves on the antenna and tends to return to the antenna. From this it is evident that a transmitting wave antenna should have a wave velocity greater than the velocity of waves in the medium in which it is used. For antennas operated in air this means that we should have a velocity greater than light. We cannot obtain real velocities greater than light but we can produce a structure in

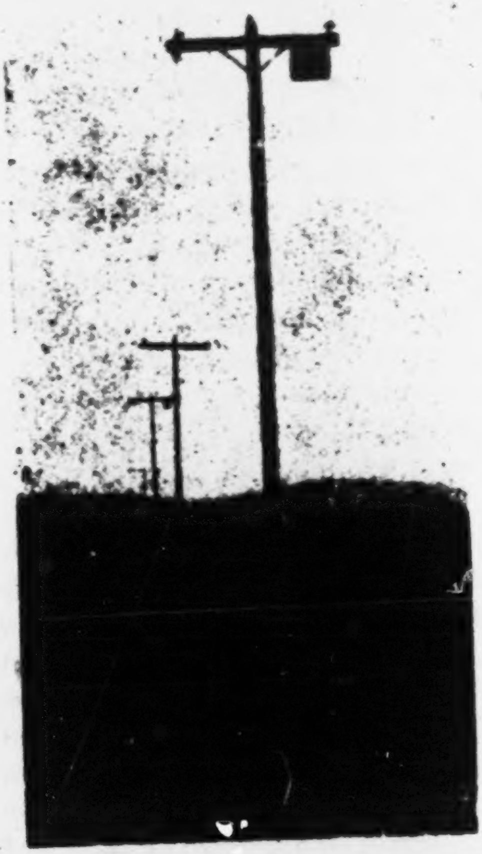

Fig. 1—Experimental wave antenna at Belfast, Maine.

which, under steady state conditions, we have an apparent or phase velocity greater than light.

(5) If a wave antenna can be given an actual velocity different from the wave velocity of the medium in which it is immersed this alone will produce a wave tilt which will result in radiation. If the actual velocity of waves on the antenna can be made greater than the velocity in the medium we can obtain considerable radiation, the amount of which increases with velocity, and which permits us to obtain very directive antennas which are also substantially aperiodic. Some interesting experiments have been made to bear out this theory by immers-

ing partially insulated radiator wires in water. In this case we do obtain an actual velocity on the wires greater than the velocity of waves in the water.

In a paper presented to the British Royal Society of Arts in July 1924,[4] Guglielmo Marconi gave publicity to his work on the development of directive short-wave systems. This stimulated world-wide short-wave development, and influenced us to undertake a careful first-hand study of the contemporary progress made in this field in England, Germany, and France. During, and immediately following this period, the engineering department of the Radio Corporation, directed by C. H. Taylor, was occupied with the development of suitable transmitting equipment, the application of this equipment to studies of propagation phenomena, and the establishment of commercial long-distance short-wave circuits.[5] The work during this period was primarily directed toward the development of efficient and reliable apparatus capable of meeting the exacting demands of short-wave communications. Meantime, the engineers of other companies associated with the Radio Corporation were working on the same problems.

The successful demonstration of the British beam circuit between England and Canada was made in 1926, proving the effectiveness of directivity. This result, together with completion of the initial apparatus development, caused us to concentrate on our study of propagation phenomena, and the development of directive antenna systems which would be efficient and sufficiently inexpensive to permit their use on a great number of our commercial long-distance circuits.

Lindenblad, who had specialized on antenna design, was added to the Rocky Point group to work exclusively on directive antenna development. He had assigned to assist him, at various times, Henry Tanck of the R.C.A., and C. F. Coombs and Paul Forrest of the General Electric Company.

In the four years which followed, four types of directive antennas were developed. These have been designated as Models A, B, C, and D. The model A system is of the broadside type, consisting of linear arrays of vertical radiators fed with a special transmission system having nearly infinite phase velocity. The model B antenna consists of one or more arrays of parallel long wires, in a vertical plane, which have their ends staggered in such a way as to give a unidirectional beam of ver-

[4] Guglielmo Marconi, "Results obtained over very long distances by short wave directional wireless telegraphy, more generally referred to as the beam system," read at a meeting of the Royal Society of Arts, July 2, 1924.

[5] Hallborg, Briggs, and Hansell, "Short-wave commercial long-distance communication," Proc. I.R.E., 15, June, 1927; H. E. Hallborg, "The radio plant of R.C.A. Communications, Inc.," Proc. I.R.E., 18, March, 1930; A. A. Isbell, "The RCA world wide radio network." Proc. I.R.E., 18, October, 1930.

tically polarized waves. The model C antenna is similar to the model B but differs in that the radiator wires are arranged in a horizontal plane and give a unidirectional beam of horizontally polarized waves. The model D antenna system consists of radiating elements made up of long wires bent into the shape of horizontal V's which are used in an array giving a unidirectional beam of horizontally polarized waves.

Development of the Model A Antenna

The development first followed the ideas brought out at Belfast, in that efforts were directed toward obtaining an efficient form of transmitting wave antenna. Great difficulty was encountered in attempting to control the velocity, current distribution, and radiation efficiency of wave antenna models.

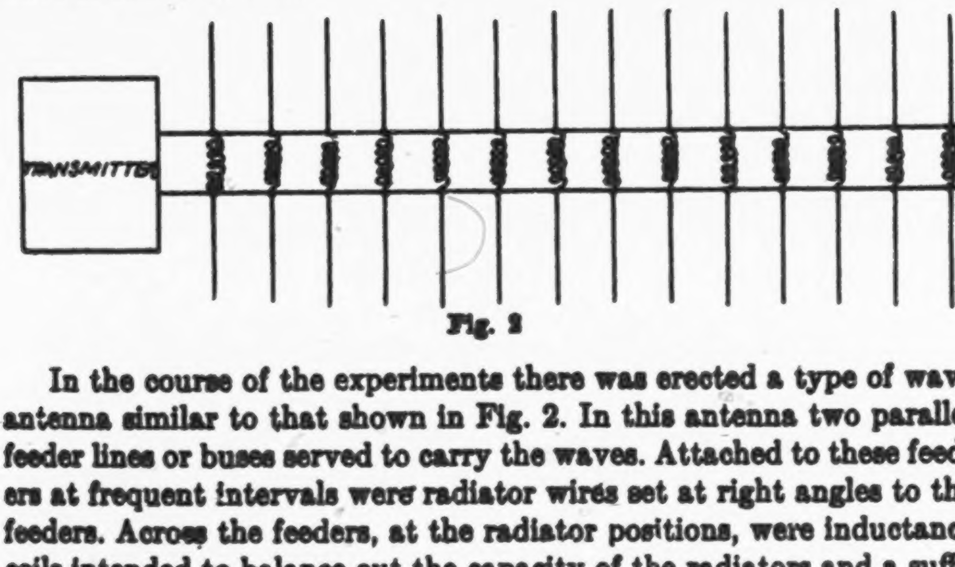

Fig. 2

In the course of the experiments there was erected a type of wave antenna similar to that shown in Fig. 2. In this antenna two parallel feeder lines or buses served to carry the waves. Attached to these feeders at frequent intervals were radiator wires set at right angles to the feeders. Across the feeders, at the radiator positions, were inductance coils intended to balance out the capacity of the radiators and a sufficient part of the feeder capacity to give a phase velocity slightly greater than the velocity of light.

In working with this model the procedure was to vary the phase velocity by varying the transmitter frequency. The current distribution in the antenna was checked and the field distribution pattern of the radiation was measured with a portable receiving antenna and sensitive thermocouple meter.

It was soon observed that if the frequency was sufficiently decreased, a point was reached where the phase velocity was substantially infinite and a good directive pattern, approximately at right angles to the antenna, was obtained. This broadside directivity was obtained so much more readily than the wave antenna effect that it was decided to build a full-scale working model of unidirectional antenna using this principle and to try it out for long-distance transmission.

The model was finished and first demonstrated by transmission from Rocky Point, New York, to Marshall, California, and Koko Head, Hawaii, on April 3, 1927.

An analysis of the power increase per unit cost for this type of antenna indicated that it could compete successfully with the British beam and other existing forms of directive antennas. It had a marked advantage in meeting our needs and permitted improvements in service by application of directivity to a large number of circuits at a moderate expense. Its use did not require risking a large loss of investment in antennas due to obsolescence.

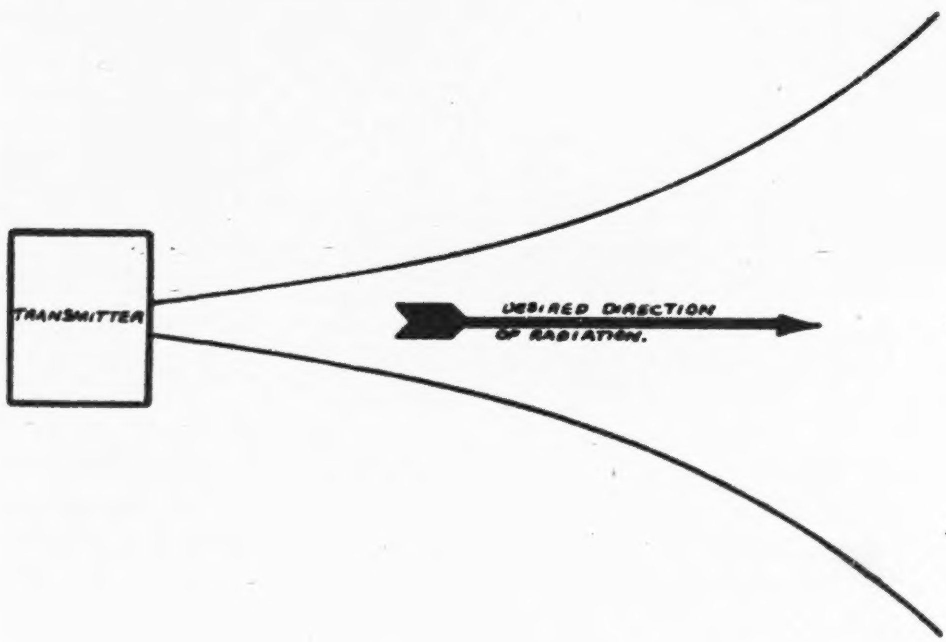

Fig. 3

The first commercial Model A antenna went into service in September, 1927. It was operated on a 16.2-meter wavelength and used the call letters 2XT and WTT. It was directed at Germany but was also useful to several other points in Europe. It soon proved itself to be a valuable addition to service and was operated successfully at traffic speeds up to 240 words per minute.

The designs of the first commercial Model A antenna system and additional antennas which were built in rapid succession were handled by Carter. Altogether 38 antennas of this type have been built and are still in use in the United States, Phillippines, Hawaii, China, Russia, and Norway.

Developments of Models B and C Antennas

During most of the period occupied by the demonstration and commercialization of the Model A antenna, in 1927 and 1928, Lindenblad was kept as free as possible to continue the forward looking development aimed at producing some practical form of transmitting wave antenna. During this period J. A. Biondo[6] was his chief assistant.

Among other ideas investigated an attempt was made to obtain radiation attenuation and directivity from a transmission line having a continuously changing characteristic impedance or a continuously changing spacing as shown in Fig. 3. The idea behind the increasing spacing was to obtain a wave tilt to produce radiation and it was hoped that sufficient attenuation might be obtained to give us an aperiodic antenna with practically a unidirectional characteristic.

In these particular experiments the results with the expanding line antenna were not very satisfactory because the attenuation was not sufficiently great. However, they served to focus attention on the radiation efficiency and directive characteristics of long wires and caused Lindenblad to consider ways of combining them to obtain sharp unidirectional characteristics. As a result he devised the directive system employed in the models B and C projector antennas. A complete description of these models is given later in this paper. For a general idea of the form of construction used refer to Figs. 22 to 26.

A small model of his antenna system, which could be made vertical to correspond to the Model B or horizontal to correspond to the Model C, was built and tested on a six-meter wavelength with promising results. At the same time Carter was following up Lindenblad's experiments by mathematical calculation and analysis. Carter's results, in general, confirmed the experimental measurements. It was therefore decided to build full-scale models for test and demonstration between Rocky Point and Marshall.

The first large Model B antenna had been constructed and tuned by February 7, 1929 and long-distance tests were started on that date. From that time until about the first of April a series of tests was made resulting in improvements in the original model in respect to radiation efficiency and angle of the beam. At the same time information was collected to enable us to design commercial antennas with dimensions which would result approximately in optimum results per dollar of cost. The final results indicated that the new antenna would be a great improvement over the Model A not only in results per dollar of cost but also in simplicity and service reliability.

[6] Mr. Biondo is now representing the R.C.A. in Italy in connection with the erection of a broadcast station in Rome.

During the early tests and demonstrations of the Model B antenna a Model C antenna was being constructed. It was finished and first used for long-distance tests on April 10, 1929. It was also carefully studied with the object of obtaining optimum economy in design and it too was found to be a great improvement over the Model A.

Since Model B and C antennas were ready for application to commercial construction at about the same time, it became necessary to make a choice between them. Upon first consideration it appeared that

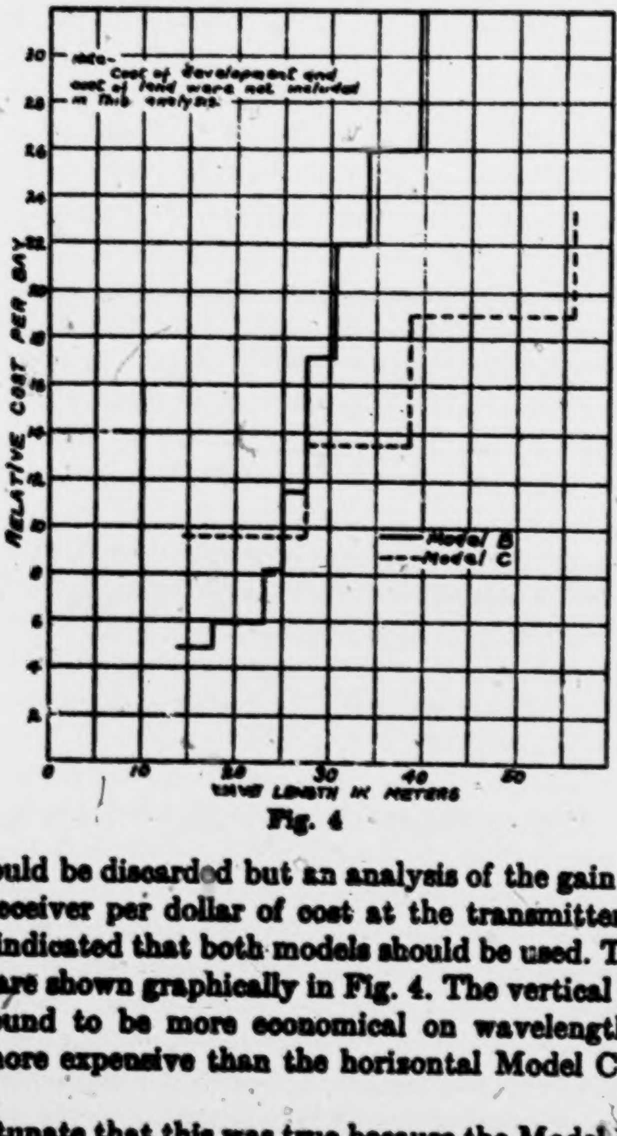

Fig. 4

one model would be discarded but an analysis of the gain in energy at the distant receiver per dollar of cost at the transmitter for various wavelengths indicated that both models should be used. The results of this analysis are shown graphically in Fig. 4. The vertical model B antenna was found to be more economical on wavelengths below 25 meters but more expensive than the horizontal Model C antenna on longer waves.

It was fortunate that this was true because the Model B antenna is better suited to increasing directivity by broadsiding several antennas to form one very directive system. A single section has sharp vertical directivity but its beam is quite broad horizontally. The broadsiding

increases only the horizontal concentration and this can be done without making the beam excessively narrow.

The beam from the Model C antenna, on the other hand, is broad vertically but very sharp horizontally, making it less suitable for broadsiding. Since the cost per section of directive antennas is high on the longer waves, where the Model C is used, there is less need for broadsiding a number of sections and the objection to the use of the Model C antenna is unimportant.

The first commercial Model B antenna was placed in service at Rocky Point on April 4, 1930. It has two broadsided sections directed on Madrid and is used on a 16.55-meter wavelength. Altogether there have been or are being built twenty-five of these antennas at Rocky Point, New York, New Brunswick and Tuckerton, New Jersey, Bolinas, California, and in the Hawaiian Islands. Sixteen of these antennas are being built by the Mutual Telephone Company of Honolulu. They are to be used for both transmitting and receiving in the system of telephone circuits to connect the islands on wavelengths of less than 10 meters.

The first commercial Model C antenna was placed in service on July 7, 1930. It has only one section, is directed on Buenos Aires and is used on a 28.22-meter wavlength. Altogether six of these antennas have been built at Rocky Point and New Brunswick.

Development of the Model D Antenna

For a brief period the engineers of the group were inclined to believe that the Models B and C came close to the ultimate in simplicity and economy and that little further improvement was attainable. There being no further ideas recognized as holding promise of immediate economic gain, Lindenblad was assigned to carry on pioneering development in another field.

Carter, with the assistance of E. D. Thorne, continued the design of antennas for commercial construction. Some of his time was given to extended tests with the Models B and C, and to further mathematical analysis with the object of obtaining a better understanding of experimental results. He immediately became interested in other combinations of long wires for obtaining directivity and, before the end of 1929, was advocating the trial of a new type of antenna which, by requiring fewer supports, promised to have an economic advantage over the three previous models. This antenna, which has some resemblance to the expanding line shown in Fig. 3, is now known as the Model D. For a general idea of its construction refer to Fig. 36.

An experimental Model D antenna was built in the first part of 1930

and long-distance tests were started in April. These tests were continued throughout the summer and fall and have resulted in the adoption of the Model D for new construction. At the present time there are built, or being built, eleven antennas of this type located at Rocky Point, New York, Bolinas, California, and Kahuku, Hawaii. The antennas at Kahuku are of particular interest because they will be used as part of the first commercial transoceanic telephone station to be operated by R.C.A. Communications, Inc.

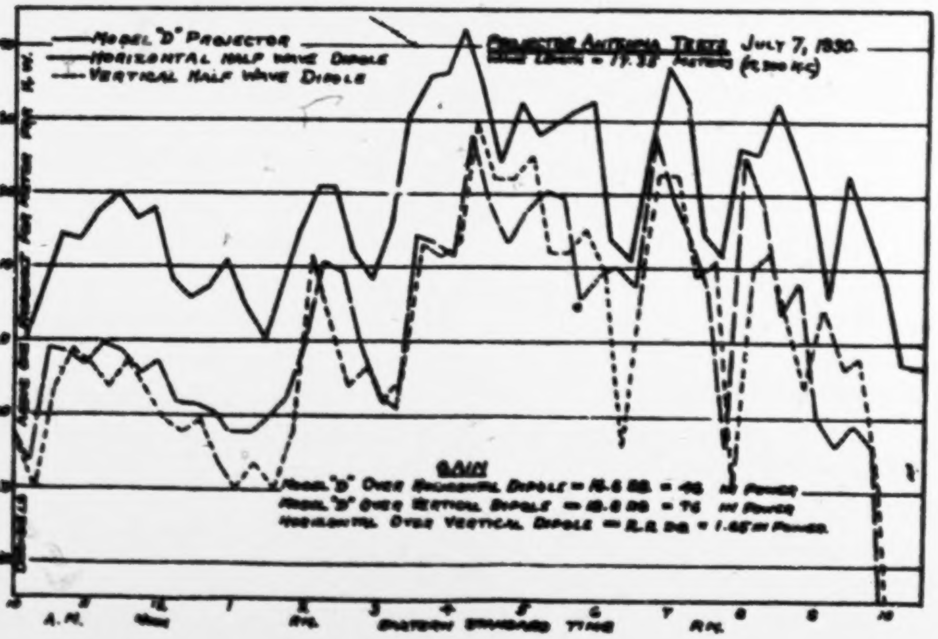

Fig. 5

Method of Testing Antennas

All of the long-distance antenna tests have been made by switching the transmitter from one antenna to another, usually at five-minute intervals. A half-wave dipole at the same height and having the same polarization as the directive antenna under test has been used as a standard of reference. In addition, many tests have been comparisons of one model of directive antenna with another.

In all cases the transmitter power has been measured for each reading by subtracting the power carried away in the cooling water from the input to the last stage of amplifier.

The relative signal strength delivered to the receiver by the antennas being compared has been measured with a calibrated receiver in the

output of which a meter was used as an indicator to average out rapid fluctuations and eliminate possible errors in judgment of the operator.

The readings have been reduced to decibels above an arbitrary reference value, per kilowatt of transmitter power. The average received signal energy in decibels for the whole day is then determined for each of the antennas under test and the difference between these figures, which is ten times the logarithm of the power ratio, is taken as

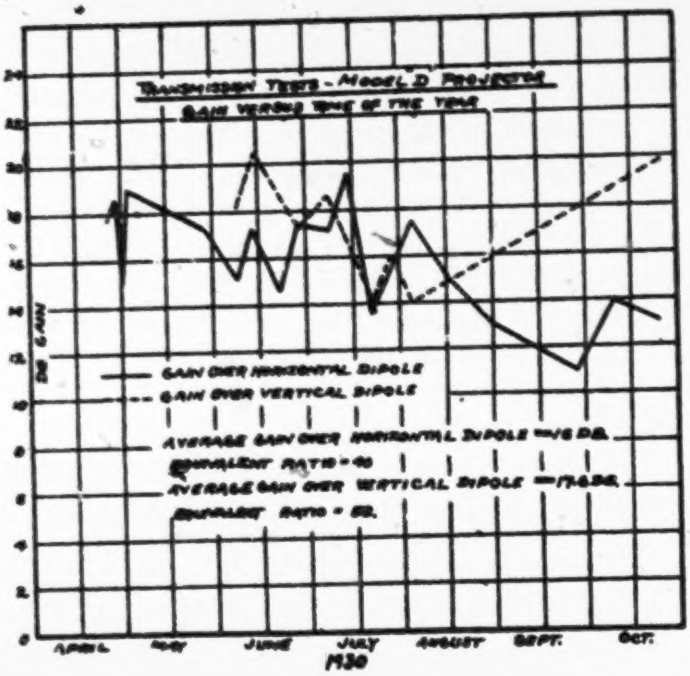

Fig. 6

the difference in effectiveness of the antennas on that day. We consider this the best method of arriving at a ratio for the extremely variable signals from short-wave antennas.

Fig. 5 shows the results of a typical day's run on a Model D antenna. Many days of tests of this sort have been made to arrive at a reliable figure of merit for each model.

Fig. 6 shows the seasonal variation in effectiveness of the Model D antenna when used for transmission from Rocky Point to Marshall on a wavelength of 17.3 meters.

We are greatly indebted to R. R. Beal of the Pacific Division and his staff, particularly I. C. Reid of the Marshall Station, for their coöperation in making thousands of signal strength measurements. The remarkable consistency of the average results in spite of the great variations in individual readings on short-wave signals indicates extraordinary care and patience on their part.

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Power Concentrations Obtained

The increase in power, due to antenna directivity, of the signal received at a distant receiving station varies to some extent with the wavelength, time of year, and the particular circuit being observed. Our long-distance tests have, in most cases, been made on wavelengths of 16 to 17 meters and over the transcontinental circuit from Rocky Point to Marshall. Some additional tests have been made over the longer circuit from Rocky Point to Hawaii. The Model A antenna was tested by comparison with a half-wave dipole for transmission from Rocky Point to Geltow, Germany. These tests checked the measurements made at Marshall with remarkable exactness.

The directivity of the Model A antenna was also checked by comparison measurements with a pick-up antenna and a sensitive thermocouple meter located at from 500 to 2000 meters in front of the dipole and directive antenna. These short-distance measurements checked the long-distance measurements at Marshall and Geltow within 10 per cent.

Using the average of a great number of experimental determinations we have arrived at the following approximate figures for the increase in power, due to directivity, from one bay of each of the four models of directive antennas.

	Decibels Gain Over Half-Wave Dipole	*Power Ratio To Half-Wave Dipole*	*Directivity*
Model A	10	10	16.4
Model B	12	16	26.3
Model C	12.4	17.5	28.7
Model D	16	40	65.6

Where a number of bays is used the increase in power ratio is very nearly in proportion to the number of bays. We have used up to four bays of the Model A, two bays of the Model B, two bays of the Model C, and two bays of the Model D. This does not mean that no greater directivity should be used, and further discussion on this point will appear later in the paper.

Study of Directive Characteristics Required

In all of the directive antenna development we have been troubled by lack of reliable information as to what directive properties an antenna should have. The uncertainties in this connection, which must also have troubled others, may be briefly summarised in the following questions:

(1) Should the beam from a directive antenna be made up of vertically polarized waves or would horizontal polarization be better?

(2) If unlimited vertical directivity is obtainable, how sharp should this directivity be made and what should be the angle of elevation of the beam with respect to the earth?

(3) Does the beam of radiation always follow the great circle path from transmitter to receiver or may it be variably deflected due to unequal refraction in the atmosphere in such a manner that very sharp horizontal directivity should not be used?

We must admit that we cannot give complete and reliable answers to these questions but we have obtained some information of practical value and have formed tentative conclusions which may be of interest to others.

In the early tests with Marshall and Koko Head a comparison was made of the signals delivered from horizontal and vertical dipoles. It was found that the horizontal dipole delivered considerably more power to Marshall but the vertical dipole was better by about an equal amount at Koko Head. Since Marshall is about 2600 miles and Koko Head 5,000 miles distant from Rocky Point, we concluded that difference in polarization was probably unimportant except in so far as it might affect the transmitting antenna efficiency and directivity. It might have a considerable effect upon the wavelength which would give best results over a given circuit at a given time of year and time of day but, throughout a year and averaging all conditions, would probably have little effect upon the average usefulness of an antenna. In general, it appears that horizontal polarization should be used on shorter circuits, or on shorter wavelengths than should vertical polarization. However, the data available are too meager to permit a reliable conclusion.

The Model B antenna has probably the greatest vertical directivity obtained in any commercial form of directive antenna. In a series of tests extending over about six months no evidence of widely varying power ratios from the sharp directivity was observed at Marshall. We are, therefore, inclined to believe that vertical directivity of the amount used in this antenna is safe so long as the correct angle of beam is used.

Since the vertical directivity of the Model B antenna is so great, it gave an opportunity to make an experimental check on the effect of elevation of the beam upon the signal received at a distance. Originally the British Marconi Company had given a rather high angle as the optimum elevation for the radiation and had indicated that their beam antennas were designed to give this high angle. Subsequently T. L.

Eckersley made a very complete and ingenious study of this problem from data obtained by facsimile transmission using vertically polarized waves and concluded that quite small angles should be used.[7] Miessner and Rothe, in Germany, arrived at the same conclusion by means of experiments with horizontally polarized waves.[8]

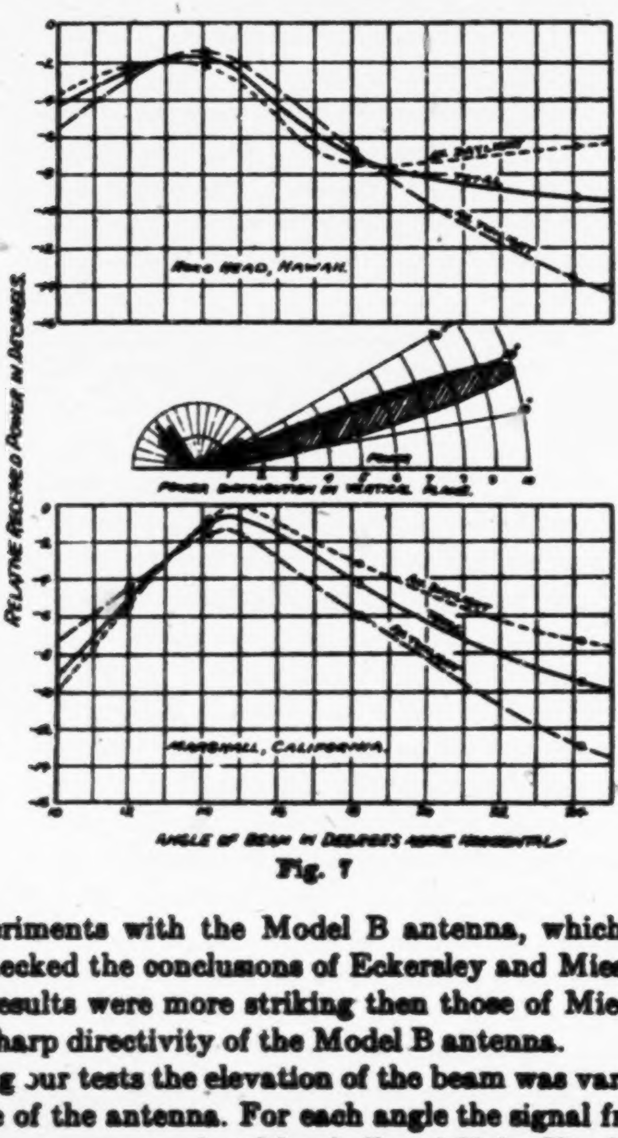

Fig. 7

Our experiments with the Model B antenna, which is vertically polarized, checked the conclusions of Eckersley and Miessner. The experimental results were more striking then those of Miessner because of the very sharp directivity of the Model B antenna.

In making our tests the elevation of the beam was varied by changing the angle of the antenna. For each angle the signal from the directive antenna was compared at Marshall and Koko Head with another antenna used as a standard. The results of the tests are shown in Fig. 7. In this figure the relative signal strengths are plotted against the true

[7] T. L. Eckersley, "Multiple signals in short-wave transmission," Proc. I.R.E., 18, 106, et. seq.; January, 1930.

[8] Meissner and Rothe, "On the determination of the optimum radiation angle for horizontal antennas," Proc. I.R.E., 17, 35, et. seq.; January, 1929.

angle of the line of maximum radiation. The sharpness with which the signal rose at Marshall may be partly due to increasing directivity from ground reflection but still it is obvious that the energy which reached the receiving station left the transmitting antenna at some low angle. The decrease in signal at very low angles is believed due to decreasing radiation efficiency and increasing ground losses near the transmitting antenna because, to get the lowest angle, the lower end of

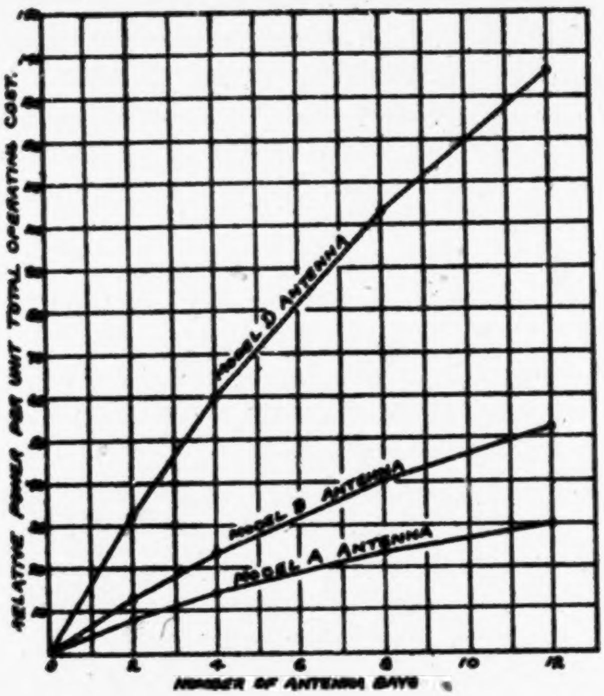

Fig. 8

the lowest radiator wire had to be run in a trench below the surface of the ground.

It will be noted that the lowest possible elevation of the beam which does not produce excessive losses in the ground is best. It may also be noted that the results at the two different distances are remarkably alike, indicating that the lowest obtainable angle is probably best for a large range of distances. Since horizontal radiation is cancelled by radiation reflected from the ground, it will be observed that the lowest obtainable angle for the center of the beam is several degrees above horizontal.

In connection with the third question we have never failed to obtain an improvement in proportion to the number of broadsided bays with any of the antenna models, except for one or two very rare and short periods. The observers at Marshall have not been able to detect any

difference in fading between a plain dipole and any of the directive antennas. It, therefore, seems probable that horizontal deflections of the beam, although they probably exist, are usually so small as to permit the use of great horizontal directivity.

Economic Value of Directive Antennas

From an engineering point of view, the money spent upon a transmitting station for interest on investment, depreciation, power, taxes, operating personnel, etc., is chiefly for the purpose of delivering signal power to the input of the distant receiver. If, by using a directive antenna, the power delivered to the receiver can be greatly increased with relatively small increase in cost, the value and efficiency of the entire investment is greatly increased.

As an illustration of the way in which our directive antennas can be used to increase the value of a transmitting station having only one 20-kw transmitter operating on a wavelength of about 20 meters, refer to Fig. 8. In this figure is shown the calculated relative received power per dollar of total cost at the transmitter for various numbers of bays of each of three types of antenna.

These curves have been calculated on the assumption that the received power is increased in proportion to the number of bays used. We have proven this to be true up to four bays of the Model A and two bays of the Models B, C, and D. Since the economic value of directivity is so great, it is obvious that a large antenna system should be used. It is hoped that data can soon be made available to show the limit beyond which the received power does not increase in proportion to the size of the antenna and the way in which the results depart from proportionality.

In applying the curves of Fig. 8 to the design of any particular transmitting station, consideration must be given to many special factors which may affect the particular station. For example, if the station is required to handle traffic to two or more receiving stations at different angles, it may be more economical to use one high power transmitter on a relatively small antenna than to use several lower power transmitters on large antennas. For an operating agency handling many circuits from one point, such as R.C.A. Communications at New York and San Francisco, the benefit from large directive antennas must be balanced against the advantages of placing a large number of transmitters in one building. The number of transmitters in one building and the size of antennas determine the length of radio-frequency transmission lines which must be used. The power losses in these lines must be considered in designing for optimum over-all economy of operations.

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From a slightly different point of view it may be noted that directive antennas make it possible to increase greatly the maximum obtainable signal power. At the present stage of development, 40 kilowatts is about the maximum practical power from any short-wave transmitter and this power radiated from a plain antenna might be insufficient for making some radio circuits commercial. By using a two-bay Model

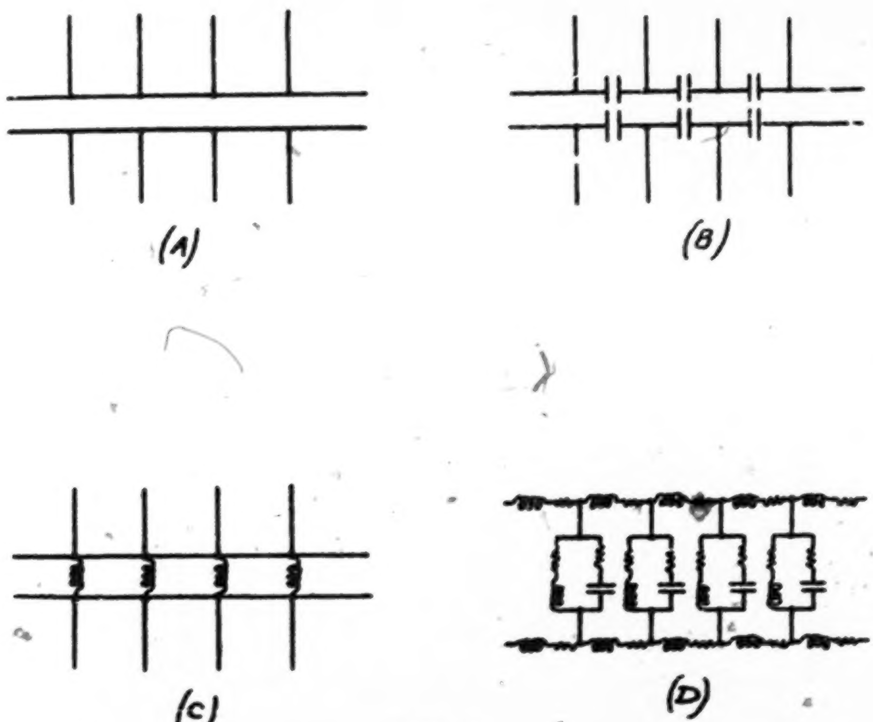

Fig. 9

D antenna, instead of a plain antenna, with a 40-kw transmitter, we may obtain an intensity in one direction equivalent to 3200 kilowatts.

It is conceivable that, before many years, the most important radio circuits may be equipped with transmitters and antennas capable of concentrating radiation in one direction equivalent to that which would be obtained in this direction with 25,000 kilowatts in a nondirective antenna.

Description of the Model A Antenna

This antenna is one in which linear arrays of vertical radiators are used. See Figs. 9 and 10. The features connected with the feeding of the radiating elements are somewhat unique. All radiators are fed in phase by a common feed line or bus system. In order that the radiators may be fed in phase, it is necessary that the velocity of phase propagation on the feed line be infinite. This does not mean that the feed energy

travels along the line at any such velocity. It merely means that by certain tuning procedure a phase phenomena can be produced which would be obtained were it possible to attain actual infinite wave velocity. Since the tuning and loading of the line is done with lumped values at regularly spaced intervals it may be proper to look at this antenna as a network rather than as a line. The choice of either viewpoint is a

Fig. 10—Four-bay model A antenna.

matter of personal taste. It may be well to use both to obtain a conception which conforms more closely with what actually takes place.

In Fig. 9, (A) represents the radiating elements attached to a common feed line. In order to obtain the correct phase of the individual radiators, the line must be broken up by series condensers as shown in (B) or shunted by inductances as shown in (C). The use of shunt coils was preferred for practical reasons. In diagram (d) we have shown the equivalent network of arrangement (C). The method of obtaining infinite phase velocity along the feeder system is similar to that used in the Alexanderson multiple tuned antenna. In the case shown in (C), (D) the phase velocity is made to approach infinity by balancing out all capacity by means of inductive shunt reactances.

The determination of optimum constants in the design of this an-

tenna system was too complicated to be solved entirely by theoretical calculations and the dimensions adopted were arrived at chiefly by experiment. It was necessary to balance radiation efficiency against the length of the antenna which could be fed from one point, by proper choice of the length of radiators and the electrical constants of the feed line. The values finally arrived at are as follows:

Length of radiators (over-all)	0.225	wavelength
Spacing between radiators	0.125	"
Maximum length of bus on each side of feed point	1.5	"
Volt ampere ratio between bus and radiators	5.	

The antenna is so designed that sleet melting current can be applied without interruption of operation.

In order to cover the necessary variation of tuning between certain standard dimensions of inductance coils, it was found convenient to make the capacity of the bus variable. This was accomplished by making each side of the line of two strips, the spacing of which was variable.

The complete antenna system includes two parallel rows of radiators placed at a spacing of five quarter wavelengths. Energy is fed to both rows of radiators of such a phase as to make the system unidirectional. The relatively large spacing between antenna and reflector elements is beneficial in reducing coupling between them. This reduces the difficulty of making the tuning adjustments and does not detract from the power gain due to directivity where both the antenna and reflector are fed from transmission lines.

The total gain in power per section of this antenna is 10 as compared with a half-wave dipole. Such a section is called a bay. We have not gone into detail in describing the action of this antenna because the general principles involved have been fully covered by Southworth.[9]

It has been found feasible to use open-wire transmission lines for feeding these antennas.[10] They compare favorably in efficiency with other types of lines. The possibility of undesired coupling between the antennas and the lines can be avoided by adherence to symmetry and selection of neutral planes in the vicinity of the antenna.

Principles of Long Linear Radiators Used in Antenna Models B, C, and D

The principles involved in the action of the three antennas whose descriptions are to follow are more or less similar and are based upon

[9] G. C. Southworth, "Certain factors affecting gain of directive antennas," Proc. I.R.E., 18, 1502–1536; September, 1930.

[10] N. Lindenblad and W. W. Brown, "Main considerations in antenna design," Proc. I.R.E., 14, 291 et. seq.; June, 1926.

the characteristics of a straight wire several wavelengths long. For this reason we shall discuss these characteristics in detail.

(a) Distribution of Radiation

It is well known that maximum radiation from a very short dipole or Hertz doublet takes place at right angles to the axis of the doublet and that the radiation in the line of the axis is zero. At a constant dis-

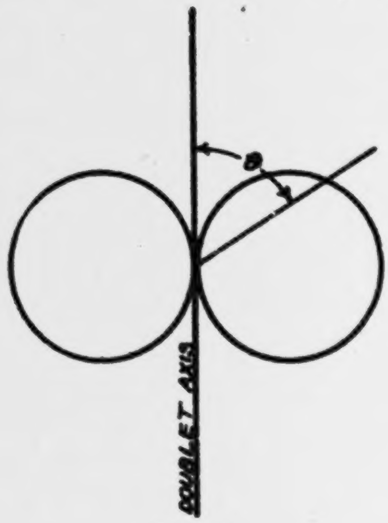

Fig. 11

tance the field intensity of the radiated wave is proportional to the sine of the angle to the axis. The plane polar diagram of relative field intensity is thus a figure eight as shown in Fig. 11. Since in a pure travel-

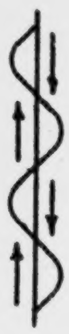

Fig. 12

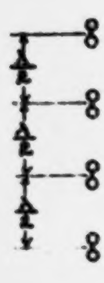

Fig. 13

ing wave the electric and magnetic intensities are equal and the intensity of energy flow is proportional to the square of either, we shall consider the electric intensity only in this discussion.

The fundamental natural frequency of oscillation for a wire in space is $c/2L$ where c is the velocity of light and L the length of the wire. Such

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a wire also has natural periods corresponding to *all* multiples of the fundamental frequency. Thus the ratios of the length of the wire to the natural wavelengths are 1/2, 2/2, 3/2, 4/2, etc. The instantaneous values of the current along a wire having a length of two waves are as shown in Fig. 12. The wire is equivalent to four half-wave dipoles placed end to end with the current reversed in each succeeding dipole. For a qualitative analysis let us replace each half-wave dipole by a doublet as shown in Fig. 13. The radiation pattern of a doublet is sufficiently near that of a half-wave dipole for present purposes.

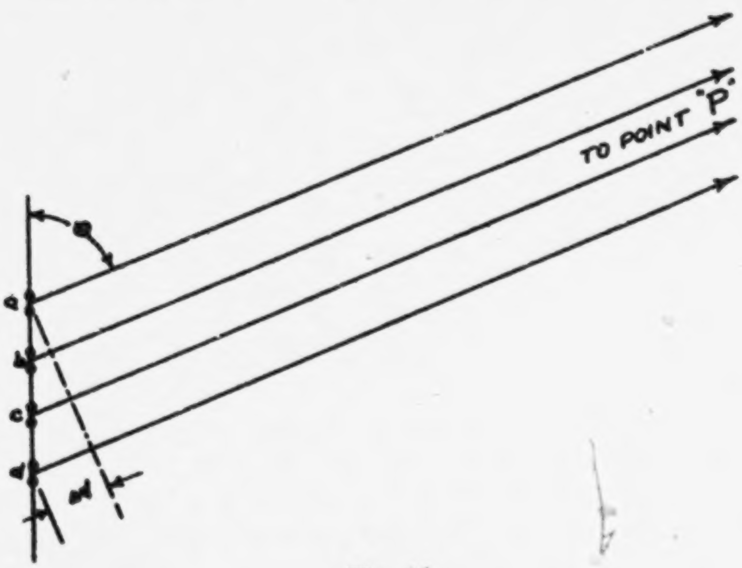

Fig. 14

Let us now go to a point P, Fig. 14, whose distance from the wire is so great in comparison with the length of the wire that the paths of wave travel may be considered parallel. The total instantaneous field at P must be the sum of the instantaneous fields due to the doublets. If the direction of P is at right angles to the wire, the field from each doublet is a maximum. Call this E. In other directions at the same distance, the field intensity for one doublet is $E \sin \theta$. Now, the distances from each doublet to P are unequal and, due to the fact that the waves travel with the velocity of light, the wave fronts will arrive at different times.

This difference in time is equivalent to a phase angle. There are similar phase differences between the waves from b and c with respect to a. The effective value of the total field at P is the vector sum of the four components.

In the direction at right angles to the axis, ($\theta = 90$ degrees) the total intensity is zero. In either direction along the axis the phase

angles between components are zero and the resultant intensity would be a maximum were it not for the fact the intensity of each component is zero. By calculation we would find a maximum at approximately 36 degrees, zero at 60 degrees, and a second maximum of lower intensity than the first at about 75 degrees.

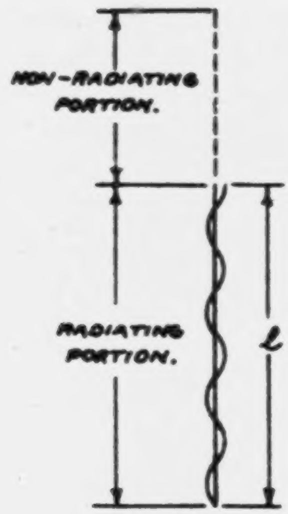

Fig. 15

Abraham[11] has treated the case of a grounded wire oscillating at one of its natural frequencies while Pierce[12] has quite completely analysed the grounded L antenna. Although the case of a wire free in space is similar in many respects to the cases already treated, it will nevertheless be analysed in detail here.

Consider a wire, the radiating portion of which has a length l. Assuming sine wave distribution the instantaneous current relationship is as shown in Fig. 15. Measuring the distance X from the free end of the wire, the current is

$$i = I \cos \omega t \sin \frac{2\pi x}{\lambda} \tag{1}$$

where $I \cos \omega t$ is the current at the antinode. Let us consider the wire as being made up of a large number of very short elements of length dX and determine the electric field e at a point P on an imaginary sphere whose radius r_0 from O is so great in comparison with the length of the wire that lines from any points on the wire to P may be considered parallel. (See Fig. 16.)

The wave from dX will arrive at P head of the wave from O due to its traveling a distance r which is less than r_0 by the amount $X \cos \theta$.

[11] *Phys. Zeit.*, 2, 1904.
[12] Electric Oscillations and Electric Waves.

A disturbance originating at O at the time t will arrive at the time $t+r_0/c$ where c is the velocity of light. Hence a wave represented by $E \cos \omega t$ at O will be represented by $E \cos [\omega(t+r_0/c)]$ at P.

At great distances from the wire the electric and magnetic fields are equal. It can be shown from the electron theory[13] that the magnetic field at any distance is the curl of Ψ where Ψ is the vector potential. At a great distance

$$\operatorname{curl} \Psi = \frac{\delta \Psi}{\delta r} \sin \theta \tag{2}$$

if we neglect $1/r^2$ as compared to $1/r$.

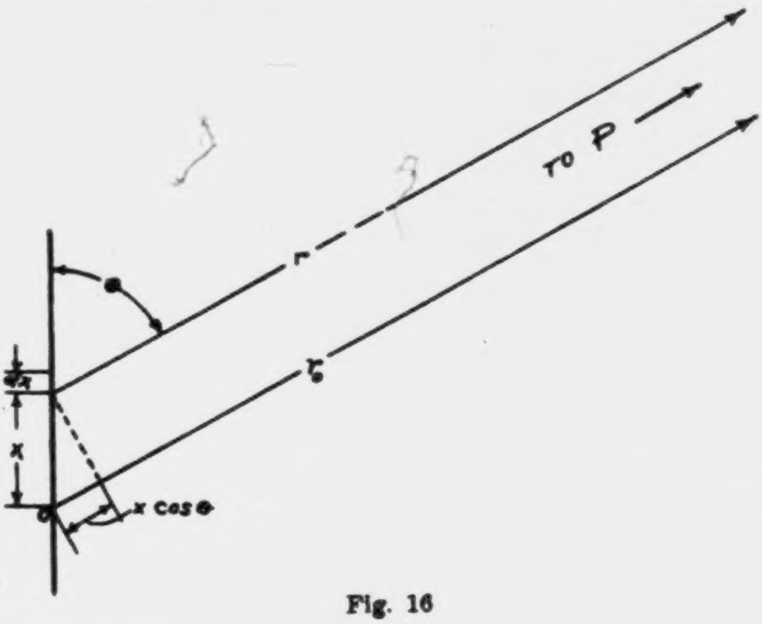

Fig. 16

Now,

$$\Psi = \frac{1}{c} \int_0^l \frac{[i]}{r} dx \tag{3}$$

where $[i]$ means that the time of travel must be properly taken into account. Hence

$$e = H = \operatorname{curl} \Psi = \sin \theta \frac{\delta}{\delta r} \int_0^l \frac{I}{c r_0} \cos \omega\left(t - \frac{r}{c}\right) \sin 2\pi \frac{x}{\lambda} \cdot dx. \tag{4}$$

To simplify operations let $\cos \omega t$ be represented by the real part of $\epsilon^{j\omega t} = \cos \omega t + j \sin \omega t$. Then, since $\sin z = \epsilon^{jz} - \epsilon^{-jz}/2$

[13] *See* Jeans', Electricity and Magnetism, or other treatments of electromagnetic theory.

$$e = \frac{I}{2j\lambda c r_0} \sin\theta \int_0^l \frac{\delta}{\delta r}\left[\epsilon^{j\omega(t-r/c)}\left(\epsilon^{j2\pi x/\lambda} - \epsilon^{-j2\pi x/\lambda}\right)\right]dx$$

$$= \frac{\pi I}{\lambda c r_0} \sin\theta \int_0^l \epsilon^{j\omega(t-r/c)}\left[\epsilon^{j2\pi x/\lambda} - \epsilon^{-j2\pi x/\lambda}\right]dx. \tag{5}$$

Since,

$$r = r_0 - x\cos\theta,\ \omega\left(t - \frac{r}{c}\right) = \omega\left(t - \frac{r_0}{c}\right) + 2\pi\frac{x}{\lambda}\cos\theta,$$

and,

$$e = \frac{\pi I}{\lambda c r_0} \sin\theta\, \epsilon^{j\omega(t-r_0/c)} \int_0^l \left[\epsilon^{j2\pi x/\lambda(1+\cos\theta)} - \epsilon^{-j2\pi x/\lambda(1-\cos\theta)}\right]dx \tag{6}$$

and, after performing the integration and several transformations, this becomes, after letting $2\pi l/\lambda = L$,

$$e = (I/cr_0)\epsilon^{j\omega(t-r_0/c)}\{\cos L\cos(L\cos\theta) + \cos\theta\sin L\sin(L\cos\theta)$$
$$- 1 + j[\cos L\sin(L\cos\theta) - \cos\theta\sin L\cos(L\cos\theta)]\}/\sin\theta. \tag{7}$$

When l is an even number of half waves $L = 2K\pi$ where K is an integer and,

$$e = \frac{2I}{cr_0}\cos(\omega t - \beta)\frac{\sin\left(\frac{L}{2}\cos\theta\right)}{\sin\theta} \tag{8}$$

When l is an odd number of half waves $L = (2K-1)\pi$ then $\cos L = -1$, and,

$$e = \frac{2I}{cr_0}\cos(\omega t - \beta)\frac{\cos\left(\frac{L}{2}\cos\theta\right)}{\sin\theta} \tag{9}$$

If n is the number of half waves on the wire $L = \pi n$ and $L/2 = n\pi/2$.

Hence, if E is the amplitude of e, we have the following two relations:

$$E = \frac{2I}{cr_0}\ \frac{\sin\left(n\frac{\pi}{2}\cos\theta\right)}{\sin\theta} \tag{10}$$

when the wire is an even number, n, of *half* waves long and

$$E = \frac{2I}{cr_0}\ \frac{\cos\left(n\frac{\pi}{2}\cos\theta\right)}{\sin\theta} \tag{11}$$

when the wire is an odd number, n, of *half* waves long.

Formula (7) is perfectly general and from it can be determined the field for any length whatever, but, for simplicity, we shall consider only the cases where the length is an exact multiple of a half wave.

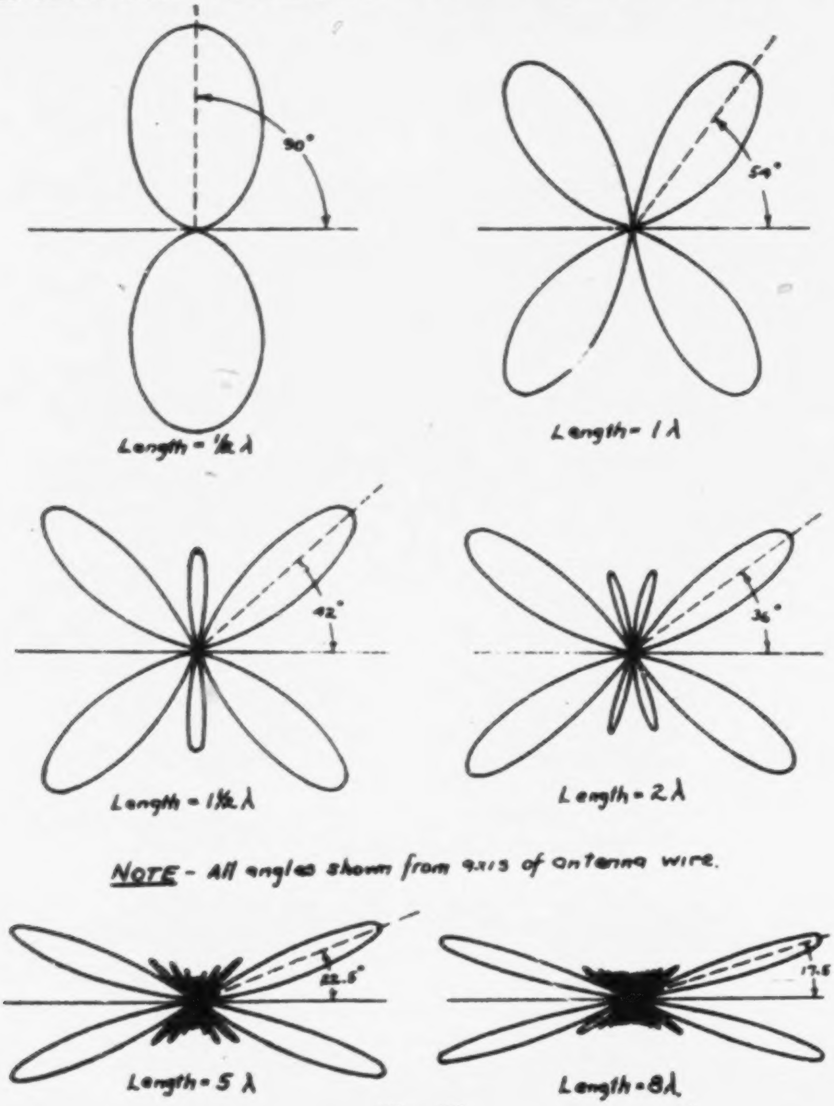

Fig. 17

Since the power flow is proportional to the square of the field amplitude, relative power distribution is obtained by squaring the values of E given by (10) or (11).

For any particular length of radiator we wish to know the angles of maximum radiation, the angles of zero radiation, and the relative amplitudes of the maxima. When n is even, for E to be zero:

$$\sin\left(n\frac{\pi}{2}\cos\theta\right) = 0, \quad n\frac{\pi}{2}\cos\theta = k\pi$$

where k is an integer and,

$$\cos\theta = 0, \frac{2}{n}, \frac{4}{n}, \cdots, \frac{n}{n} \tag{12}$$

When n is odd, for E to be zero:

$$\cos\left(n\frac{\pi}{2}\cos\theta\right) = 0, \quad n\frac{\pi}{2}\cos\theta = (2k-1)\frac{\pi}{2},$$

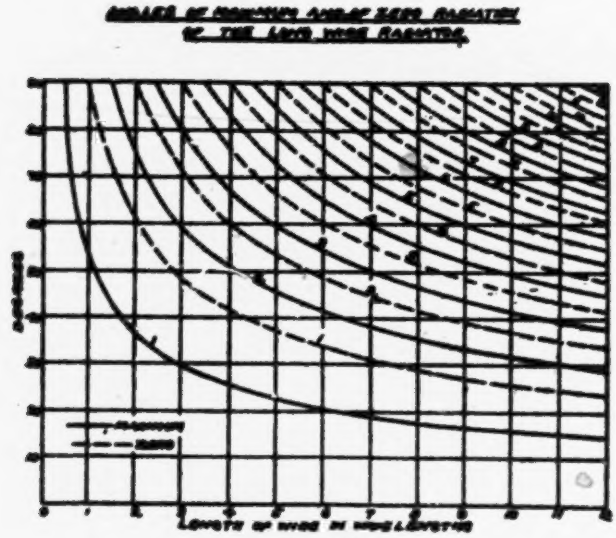

Fig. 18

and,

$$\cos\theta = \frac{1}{n}, \frac{3}{n}, \frac{5}{n}, \cdots, \frac{n}{n}. \tag{13}$$

When E is a maximum $dE/d\theta = 0$ from which we obtain:

$$\tan\left(n\frac{\pi}{2}\cos\theta\right) = -n\frac{\pi}{2}\tan\theta\sin\theta \tag{14}$$

when n is even, and,

$$\tan\left(n\frac{\pi}{2}\cos\theta\right) = n\frac{\pi}{2}\tan\theta\sin\theta \tag{15}$$

when n is odd

The values of θ for which E is maximum are obtained by solving these two equations graphically. The relative amplitudes of the maxima are obtained by substituting the values of θ obtained from (14) and (15) in (10) and (11). Fig. 17 shows several polar diagrams for wires of various lengths.

Fig. 18 is a chart showing the angles for which maximum and zero radiation takes place for all lengths of wire up to 14 wavelengths. Figs. 19 and 20 are charts showing the relative amplitudes of the maxima. These charts enable one to plot very quickly in a rough way the radiation characteristic for a wire of any length

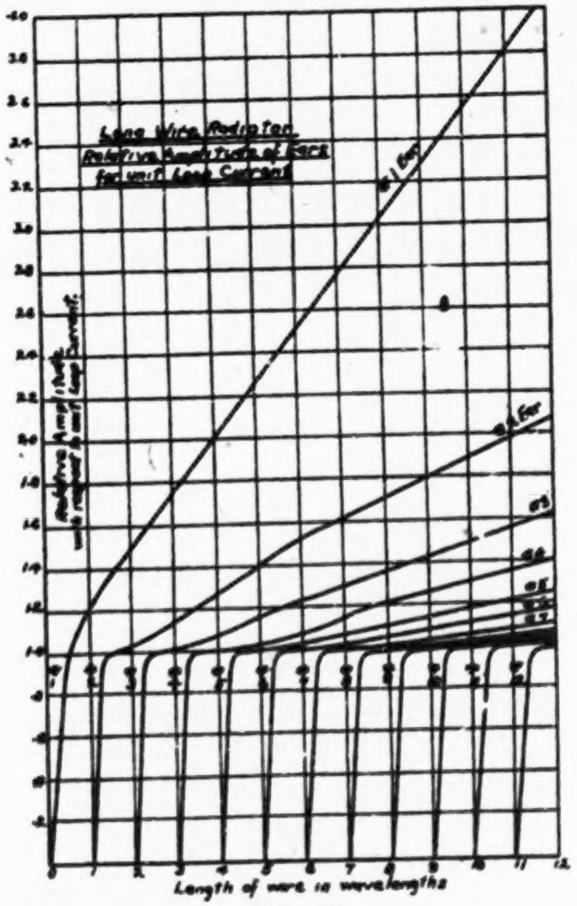

Fig. 19

(b) Radiation Resistance

The radiation resistance may be defined as the ratio of the total power radiated to the square of the current at a current antinode. All the power radiated must flow through such an imaginary sphere as we have been considering. Therefore, if we divide the surface of the sphere into small areas and sum up the power flowing through all these small areas we shall have the total power.

The power per unit area flowing through the surface of the sphere (Poynting's vector) is

$$P = \frac{c}{4\pi} e^2. \tag{16}$$

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752

Hence, the total power, dW, flowing through a small area dS is:

$$dW = Pds = \frac{c}{4\pi} e^2 ds. \tag{17}$$

Our element of area is:

$$dS = 2\pi r^2 \sin\theta d\theta \tag{18}$$

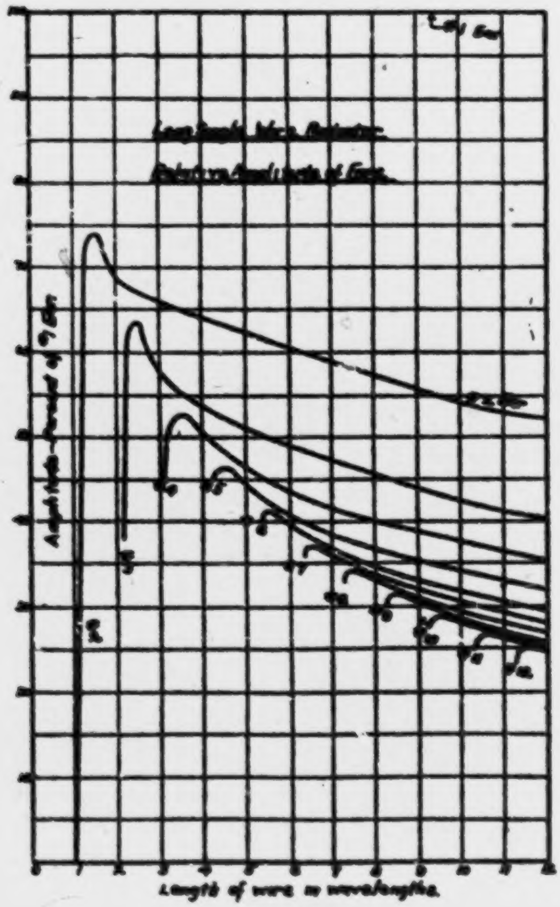

Fig. 20

hence,

$$dW = \frac{ce^2}{2} r^2 \sin\theta d\theta. \tag{19}$$

For the case of an even n we obtain, by substituting the value of e from (10) into (19):

$$dW = \frac{2I^2}{c} \sin^2(\omega t + \beta) \frac{\sin^2\left(n\frac{\pi}{2}\cos\theta\right)}{\sin\theta} d\theta. \tag{20}$$

The total power through the whole surface is then:

$$W = \frac{4I^2}{c}\sin^2(\omega t+\beta)\int_0^{\pi/2}\frac{\sin^2\left(n\dfrac{\pi}{2}\cos\theta\right)}{\sin\theta}\,d\theta. \tag{21}$$

To evaluate the above definite integral let $\cos\theta = u$. Then $du = -\sin\theta\, d\theta$ and $\sin\theta = \sqrt{1-u^2}$ and, calling the integral J,

$$J = \int_0^{\pi/2}\frac{\sin^2\left(\dfrac{n\pi}{2}\cos\theta\right)}{\sin\theta}\,d\theta = -\int_1^0\frac{\sin^2\left(\dfrac{n\pi}{2}u\right)}{\sqrt{1-u^2}}\,\frac{du}{\sqrt{1-u^2}}$$

$$= \int_0^1\frac{\sin^2\left(\dfrac{n\pi}{2}u\right)}{1-u^2}\,du = \frac{1}{2}\int_0^1\frac{1-\cos n\pi u}{1-u^2}\,du$$

but, since

$$\frac{1}{1-u^2} = \frac{1}{2}\left[\frac{1}{1+u}+\frac{1}{1-u}\right]$$

$$J = \frac{1}{4}\int_0^1\frac{1-\cos n\pi u}{1+u}\,du + \frac{1}{4}\int_0^1\frac{1-\cos n\pi u}{1-u}\,du$$

$$= \frac{1}{4}\int_0^1\frac{1-\cos n\pi u}{1+u}\,du + \frac{1}{4}\int_{-1}^0\frac{1-\cos n\pi u}{1+u}\,du$$

$$= \frac{1}{4}\int_{-1}^{+1}\frac{1-\cos n\pi u}{1+u}\,du.$$

Let $n\pi(u+1) = \phi$ then $n\pi u = \phi - n\pi$ and $du = d\phi/n\pi$, and

$$J = \frac{1}{4}\int_0^{2\pi n}\frac{1-\cos(\phi-n\pi)}{\phi}\,d\phi$$

$$= \frac{1}{4}\int_0^{2\pi n}\frac{1-\cos\phi}{\phi}\,d\phi$$

since $\cos(\phi - n\pi) = \cos\phi$, and

$$W = \frac{I^2}{c}\sin^2(\omega t+\beta)\int_0^{2\pi n}\frac{1-\cos\phi}{\phi}\,d\phi \tag{22}$$

or,

$$W = \frac{I^2}{c}\sin^2(\omega t+\beta)\left[\log_e 2\pi n + \gamma - Ci(2\pi n)\right] \tag{23}$$

where, $x = 0.5772 + \cdots =$ Eulers constant, and

$$Ci(2\pi n) = \int_{\infty}^{2\pi n} \frac{\cos\phi}{\phi} d\phi.$$

Tables and curves of $Ci\ (x)$ are given in the appendix to Steinmetz' "Transient Electric Phenomena" and Jahnke-Emde's "Functiontafeln mit Formeln und Kurven."

For values of n greater than 2, $Ci\ (2\pi n)$ can be neglected in comparison with $\log_e (2\pi n)$ and

$$W = \frac{I^2}{c} \sin^2 (\omega t + \beta) [\log_e 2\pi n + 0.5772] \tag{24}$$

(approximately) when $n > 2$.

The radiation resistance is then:

$$R = \frac{W}{I^2 \sin^2 (\omega t + \beta)} \tag{25}$$

or,

$$R = \frac{1}{c} [\log_e 2\pi n + 0.5772 - Ci(2\pi n)] \tag{26}$$

in electrostatic cgs units, or,

$$R = \frac{1}{c} \cdot \frac{c^2}{10^9} \cdot [\quad] = 30 [\log_e 2\pi n + 0.5772 - Ci(2\pi n)] \text{ ohms} \tag{27}$$

and,

$$R = 17.23 + 30 \log_e (2\pi n) \text{ ohms.} \tag{28}$$

(approximately) when $n > 2$.

A similar analysis for the case of a wire an odd number of wavelengths long results in formulas identical with those just given. A curve of radiation resistance versus length of radiator is shown in Fig. 21.

(c) *Directivity*

To date there has been no standard quantative definition for directivity. For the present purpose we shall define this term as follows: "Directivity is the ratio of the power per unit solid angle flowing in the direction of maximum radiation to the average power per unit solid angle flowing in all directions from a radiating system." In this discussion we shall define unit solid angle as the solid angle subtended by unit area on a sphere of unit radius. Thus the total solid angle subtended by

any sphere is 4π. On a sphere of radius r the solid angle subtended by an area S is S/r^2.

Poynting's vector, P, has already been defined as the power per unit area flowing through the surface of a sphere. Hence for any sphere of radius r the power per unit solid angle is Pr^2. If P_m is the value of P in the direction of maximum radiation and W the total power radiated,

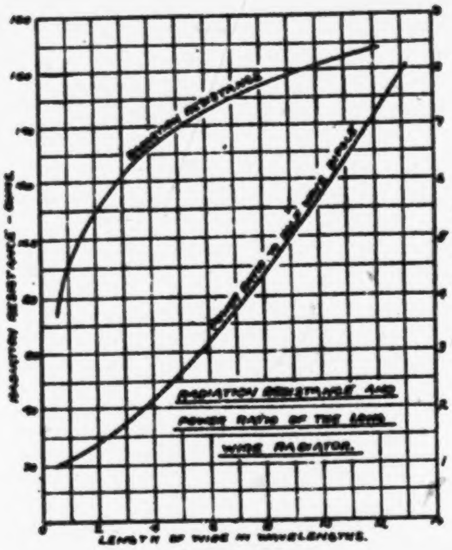

Fig. 21

then the average power per solid radian is $W/4\pi$ and, for the directivity, we have the relation:

$$D = \frac{4\pi r^2 P_m}{W} = \frac{cr^2 e_m^2}{W}. \tag{29}$$

Since the total power W is the surface integral of P over the sphere and $P = c/4\pi e^2$ we obtain:

$$D = \frac{cr^2 e_m^2}{\frac{1}{4\pi}\iint_S ce^2 dS} = \frac{4\pi r^2 e_m^2}{\iint_S e^2 dS}. \tag{30}$$

In the general case where the field intensity varies both with latitude and longitude, the element of area on the sphere is:

$$dS = r^2 \sin\theta d\theta d\phi.$$

In the particular case of a linear radiator where the intensity varies with the latitude only, we can take as our element of area a narrow zone for which $dS = 2\pi r^2 \sin\theta d\theta$.

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Thus in the general case:

$$D = \frac{4\pi e_m^2}{\int_0^{2\pi}\int_0^{\pi} e^2 \sin\theta d\theta d\phi} \tag{31}$$

and in the special case of a single linear radiator:

$$D = \frac{4\pi r^2 e_m^2}{2\pi r^2 \cdot 2\int_0^{\pi/2} e^2 \sin\theta d\theta} = \frac{e_m^2}{\int_0^{\pi/2} e^2 \sin\theta d\theta} \tag{32}$$

In practical work we use as a standard for comparing the relative directivity of directional systems the half-wave dipole. By using the value of e from (11) for $\theta = 90$ degrees (the angle of maximum radiation for the half-wave radiator) and the value of W from (23), and then substituting in (32) we obtain:

$$D = \frac{4}{\log_e 2\pi + 0.5772 - Ci(2\pi)} = \frac{4}{2.44} = 1.64 \tag{33}$$

for the half-wave dipole.

Incidentally, the radiation resistance determined by (28) is $30 \times 2.44 = 73.2$ ohms.

In some cases the very short dipole (Hertz doublet) is used as a standard of comparison. Its directivity is 3/2.

From (10) and (28) the directivity of wires an even number of half wavelengths long is:

$$D = \frac{1}{\log_e 2\pi n + 0.5772 - Ci(2\pi n)} \cdot \frac{\sin^2\left(\frac{n\pi}{2}\cos\theta_m\right)}{\sin^2\theta_m} \tag{34}$$

$$= \frac{120\sin^2\left(\frac{n\pi}{2}\cos\theta_m\right)}{R\sin^2\theta_m}$$

where θ_m is the angle of maximum radiation and R the radiation resistance in ohms.

For wires an odd number of half waves long the directivity is:

$$D = \frac{1}{\log_e 2\pi n + 0.5772 - Ci(2\pi n)} \cdot \frac{\cos^2\left(\frac{n\pi}{2}\cos\theta_m\right)}{\sin^2\theta_m} \tag{35}$$

$$= \frac{120\cos^2\left(\frac{n\pi}{2}\cos\theta_m\right)}{R\sin^2\theta_m}$$

The power ratio to the half-wave dipole for any directional antenna system is $D/1.64$ or $0.61\ D$. The power ratio to the Hertz doublet is $2/3\ D$.

In Fig. 21 are shown curves of radiation resistance and power ratio to the half-wave dipole plotted as a function of length.

Description of Antenna Models B and C

(a) General Description

The antenna Models B and C are made up by combining long linear radiators in such a manner as to obtain a unidirectional characteristic.

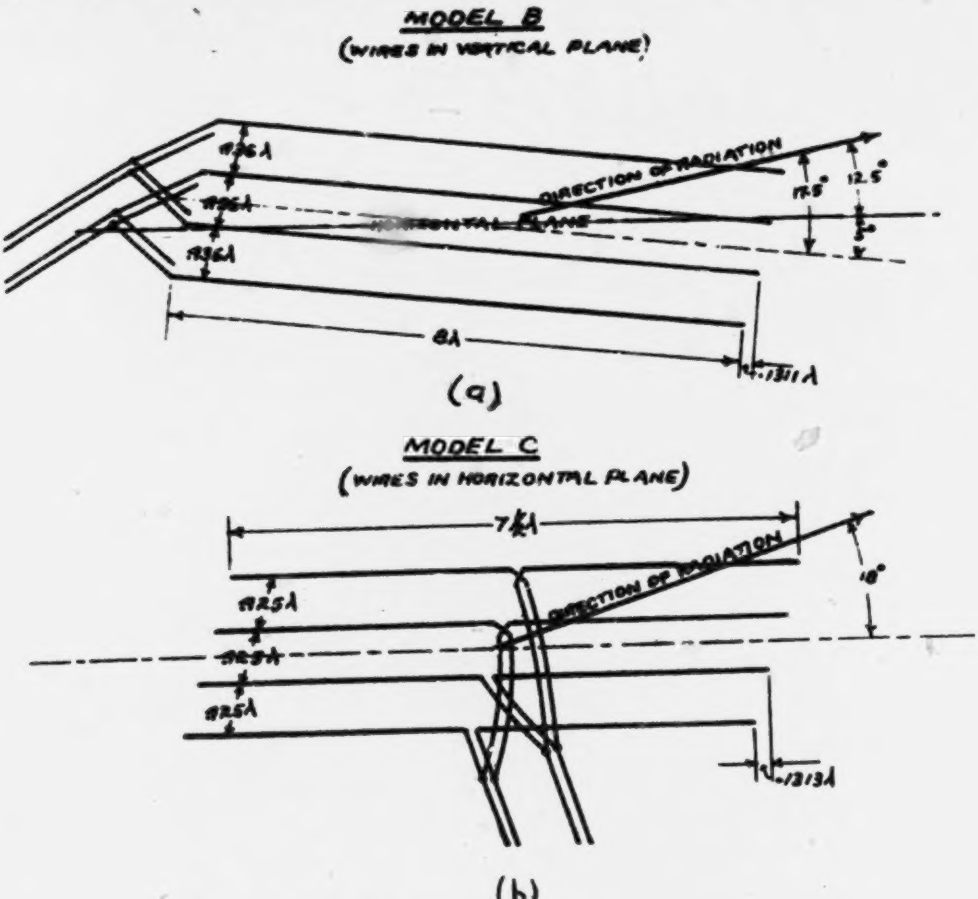


Fig. 22

The two models are very similar. The chief difference between them is that the Model B uses an array of wires in a vertical plane giving vertically polarized radiation whereas the radiators in the Model C are arranged in a horizontal plan(and radiate horizontally polarized waves.

Fig. 23--A commerical type of Model B antenna.

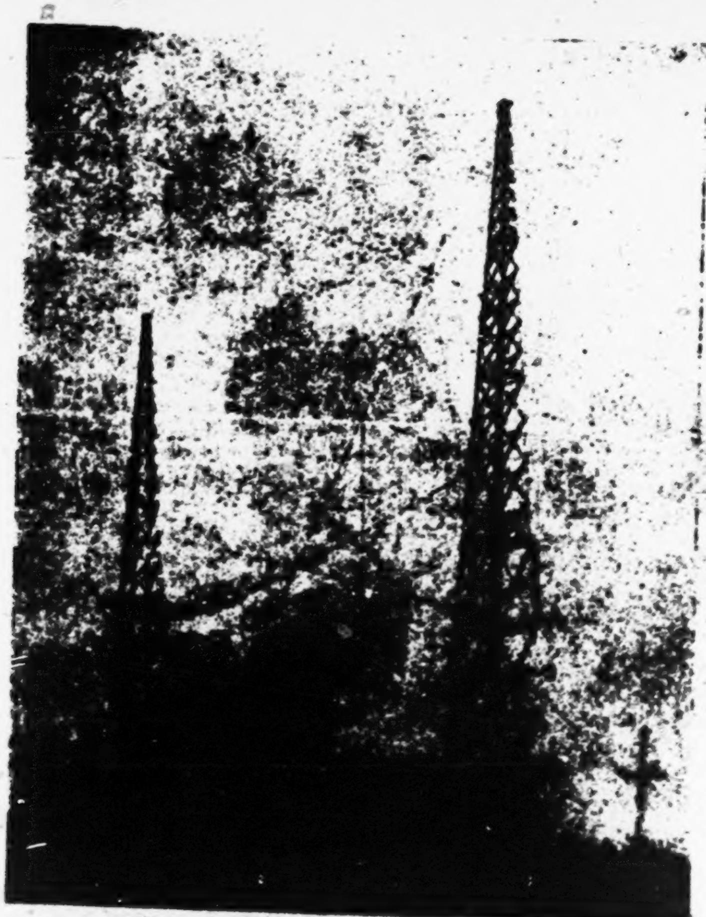


Fig. 24—Feeder details of Model B antenna.

According to the fundamentals of directive antenna technique, a certain concentration or gain of radiation in a special direction calls for

the spreading out over certain physical dimensions of the arrays of individual radiators. Therefore, the simpler the arrangement of these

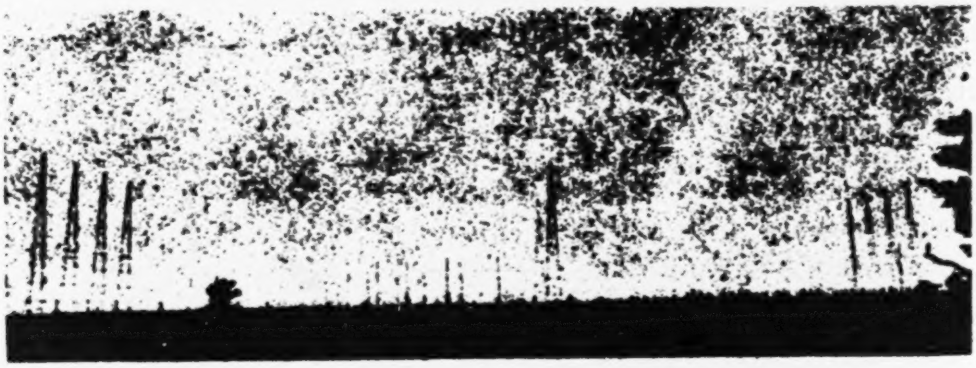


Fig. 25—A commercial type of Model C antenna.

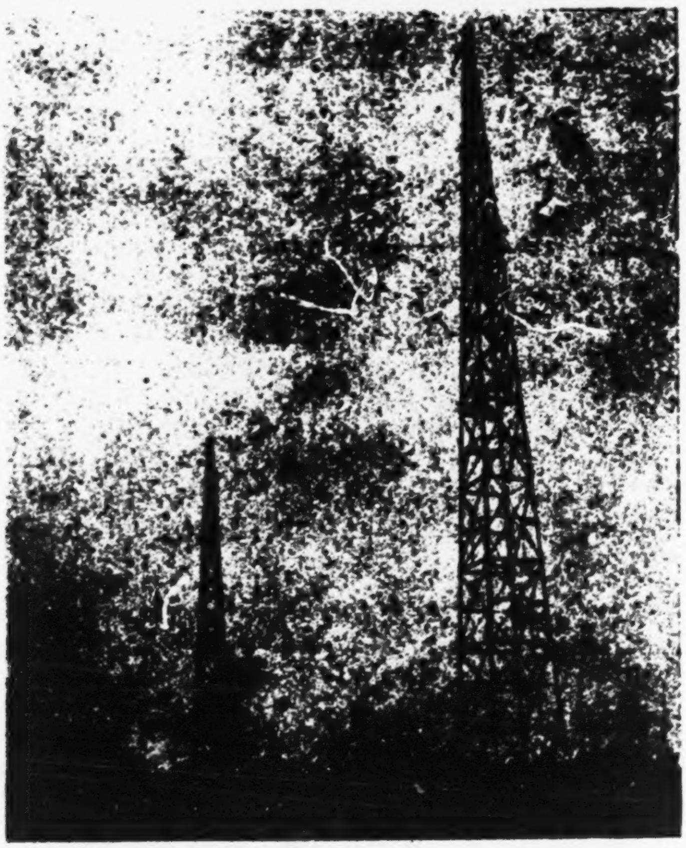


Fig. 26—Feeder details of Model C antenna.

arrays the less expensive will be the structure. The combination of several long linear radiators offers the simplest possible way of doing this. The antenna Models B and C resulted from an effort to obtain the

best possible combination of these radiators. In these models the wires are all in one plane and so staggered as to obtain a unidirectional characteristic.

One section, or bay, of these antennas consists essentially of four parallel wires, each approximately eight waves long. (See Figs. 22, 23, 24, 25, and 26.)

The vertical antenna, Model B, shown in Figs. 23 and 24, is so constructed that the maximum radiation takes place at an angle of 17.5 degrees upward from the antenna wires but 12.5 degrees upward from the ground.

The horizontal antenna, Model C, shown in Figs. 25 and 26, radiates at an angle of 18 degrees from the longitudinal center line of the antenna. The four wires are arranged in a plane parallel to the ground and at the most economical height. Tests have shown that a minimum

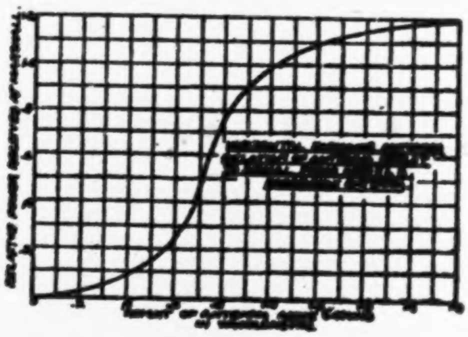


Fig. 27

height of one wavelength should be used, except in case of the longer waves, where the cost of supports is prohibitive. Fig. 27 shows the effect of varying the height above ground of a Model C antenna used on a wavelength of 16.7 meters.

When great directivity is required, several bays are broadsided on the same front at right angles to the direction of transmission and fed cophasially. In connection with the vertical model it was found particularly important to find the optimum spacing between bays. An experimental curve revealed that for two bays this spacing should be about two wavelengths. This was in accordance with the results of theoretical analysis.

It will be noted that the horizontal model may be broadsided either by a parallel arrangement or, in the case of an even number of bays, by reversing the stagger of every other bay, thus letting two adjacent bays form a "*V*." This gives a perfectly symmetrical layout and may, at times, fit in better with the shape of the available ground areas.

A special analysis of the possibilities of using steel towers was carried out.

The features in favor of steel towers are:

1. Saving of space (due to absence of guys)
2. Cleaner design
3. More permanent construction
4. Somewhat lower total cost

Of these points, Nos. 1, 2, and 3 are obvious. A careful detailed study of relative costs bore out point No. 4.

The outstanding objection to the use of steel towers was that they might affect the electrical characteristics of the antenna. It was believed that it should be possible to use steel towers without detrimental effects.

The tests carried out to verify this assumption consisted of imitating a steel tower by surrounding the wooden masts with cables in the form of a skirt.

It was found that the current set up in these cables was too small to be measured by ordinary measuring instruments and that it could be measured only by a tuned circuit indicator (a wave meter). It was attempted to produce particulary bad conditions by adjusting the length of the steel cables so as to tune to the frequency used. There was, however, very little effect obtained. Measurements of signal strength locally as well as at distant points showed the efficiency of the antenna to be unaffected by the presence of the steel cables. On the basis of these experiments steel towers were adopted.

(*b*) *Explanation of Action*

As previously explained, the radiation from a long linear radiator takes place in concentric cones. The radiation from a parallel pair of such radiators carrying currents of opposite phase will cancel in a direction perpendicular to the plane of these radiators. The radiation is then maximum in the plane of the wires and at angles coinciding with the angles of the cone.

With the pair of parallel radiators we get four main lobes of radiation, as shown in Fig. 28, having their maximum intensity in the plane of the wires. The intensity of these lobes in other planes through the axis *AA* decreases gradually to zero as we approach a plane perpendicular to the plane of the wires.

By staggering the ends of the wires, two of the four lobes are eliminated. This is done by arranging the two wires in the pair so that a line drawn through the ends of the wires forms an angle β with the axis

A-A, which is the complement of the angle α of maximum radiation with respect to the same axis. (See Fig. 29.)

In the direction *B* all points on one wire in the pair have a corresponding point on the other wire of opposite phase and on the same wave front in the direction *B*. Therefore, cancellation takes place in this direction. Cancellation also takes place in the direction opposite to

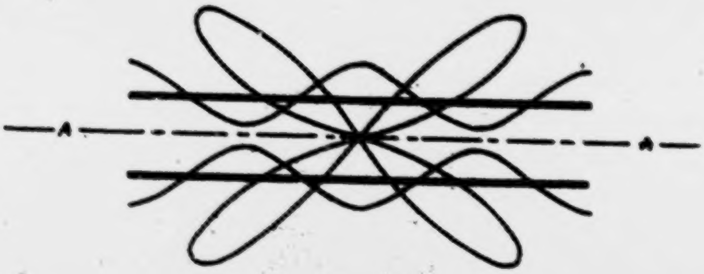


Fig. 28

B. The combination of two wires in this fashion constitutes the element on which the antenna Models B and C are based. The optimum spacing between the two wires is then the one which makes the radiation from two corresponding points on the pair add perfectly in the direction *D* of the remaining two lobes. This takes place when the distance $c=\lambda/2$.

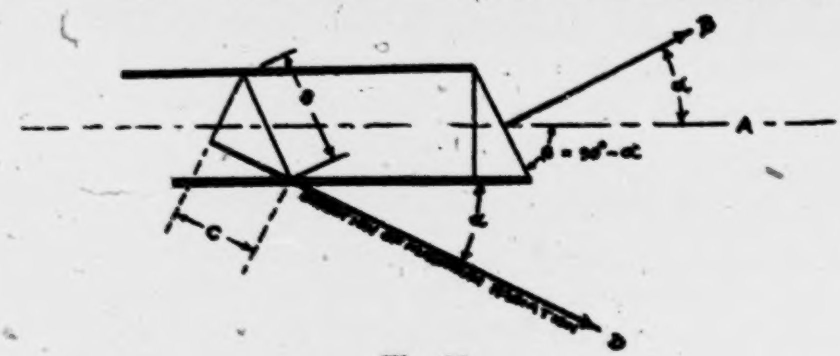


Fig. 29

The back ear is now eliminated by introducing a similar pair of wires at quarter-wave phase and quarter-wave space relation to the first pair. This is illustrated in Fig. 30(A).

The two antenna wires are designated by *A* and the two reflector wires by *R*. The pair *A* is identical with the pair *R* and both are identical with the pair previously described and shown in Fig. 29. One of the wires *R* (Fig. 30(A)) is sandwiched halfway between the wires *A* and the other falls outside one of these wires at an equal distance. The spacing between corresponding points on one reflector wire and its adjacent antenna wire then becomes $c/2$ or $\lambda/4$ in the chosen direction of radia-

tion. If R_1 leads A_1 by a 90-degree phase angle the space difference will cause cancellation of this lead in direction D and the two will add up their radiation in that direction. In the opposite direction the angle of lead is increased from 90 to 180 degrees due to the quarter-wave space difference, and cancellation will take place in that direction. A unidirectional beam is thus obtained.

One of the advantages of this arrangement wherein it differs from broadside methods, is that concentration is obtained both vertically and horizontally. This is a characteristic inherent with all end-on methods.

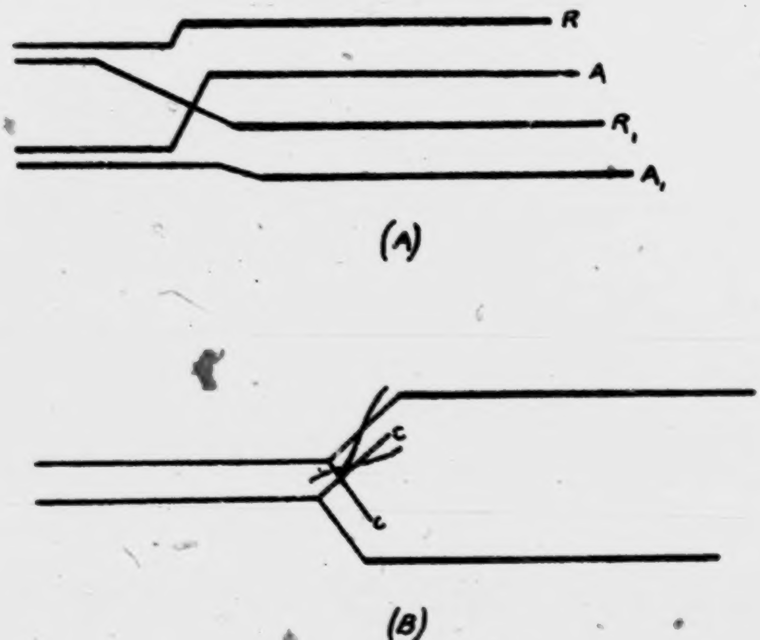


Fig. 30

As the wires in each pair are rather far apart, care must be taken that the connecting leads to the feeding transmission line do not cause unwanted radiation. One way to do this, which is the method used in the Model B antenna, is shown in Fig. 30(B). The length of the wires is so chosen as to produce opposing waves in the canceling sections C.

(c) *Tuning and Impedance Matching Circuits*

A convenient method by which tuning and phasing of the antenna circuits can be conveniently carried out has been developed. The arrangements used are shown in Fig. 31.

The short circuits S_1 and S_2 are so adjusted as to tune the antenna and connecting feed lines. The distance a is adjusted so that the

impedance at p_1 matches that of the quarter wave long connection between p_1 and p_2. Thus there will be no reflection on this line and it will have only traveling waves. This being the case, it acts as a phase rotator giving a rotation of 90 degrees between p_1 and p_2. The distance b is so adjusted that the antenna and reflector carry equal currents. The distance c is so adjusted that there is no reflection on the line from the transmitter. The short circuit S_3 is always kept one-quarter wavelength from point p_4 to kill end effect.

For the longer waves the dimensions of this form of tuning circuit become inconvenient and the more compact matching devices consisting of lumped inductances and capacities are used.

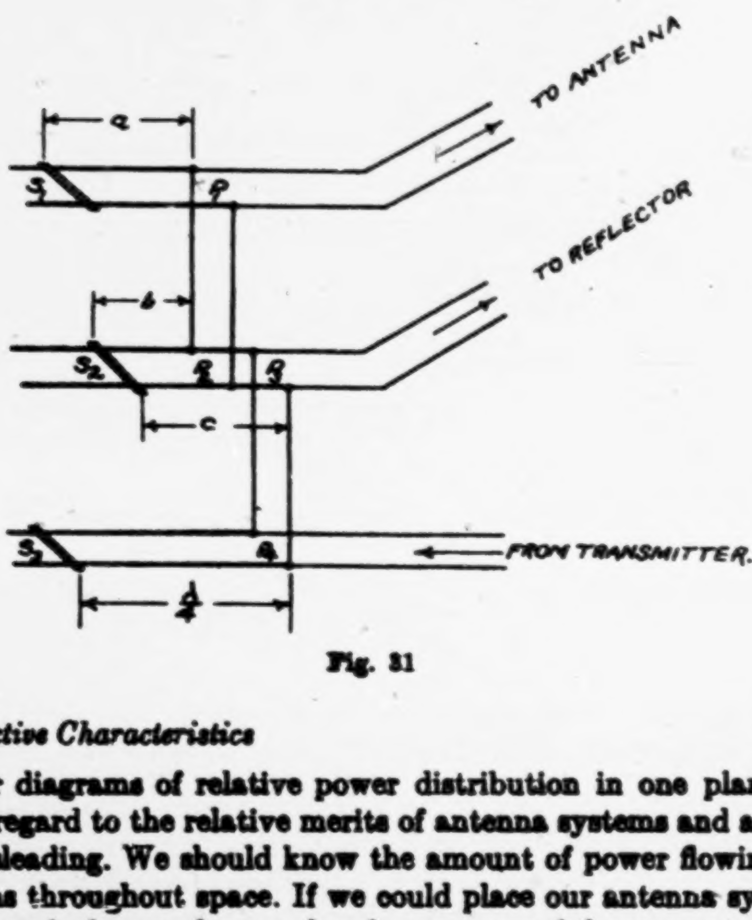


Fig. 31

(*d*) *Directive Characteristics*

Polar diagrams of relative power distribution in one plane show little in regard to the relative merits of antenna systems and are often very misleading. We should know the amount of power flowing in all directions throughout space. If we could place our antenna system at the center of a large sphere and make a survey of the amount of power flowing through each unit area of this sphere, our knowledge would be complete. If, from this data, we were to plot contour lines of equal intensity on a small sphere we should obtain an excellent picture of what takes place. Finding the sphere unhandy for use, we could cut it in half at the equator and project each hemisphere with its contour

lines and its coördinate lines of latitude and longitude on a plane sheet of paper Such a diagram is, of course, distorted in area but presents a good picture of the distribution of radiation. Figs. 32 and 33 are examples of such diagrams and show the characteristics for one and two bays respectively of the Model B antenna. It will be seen from

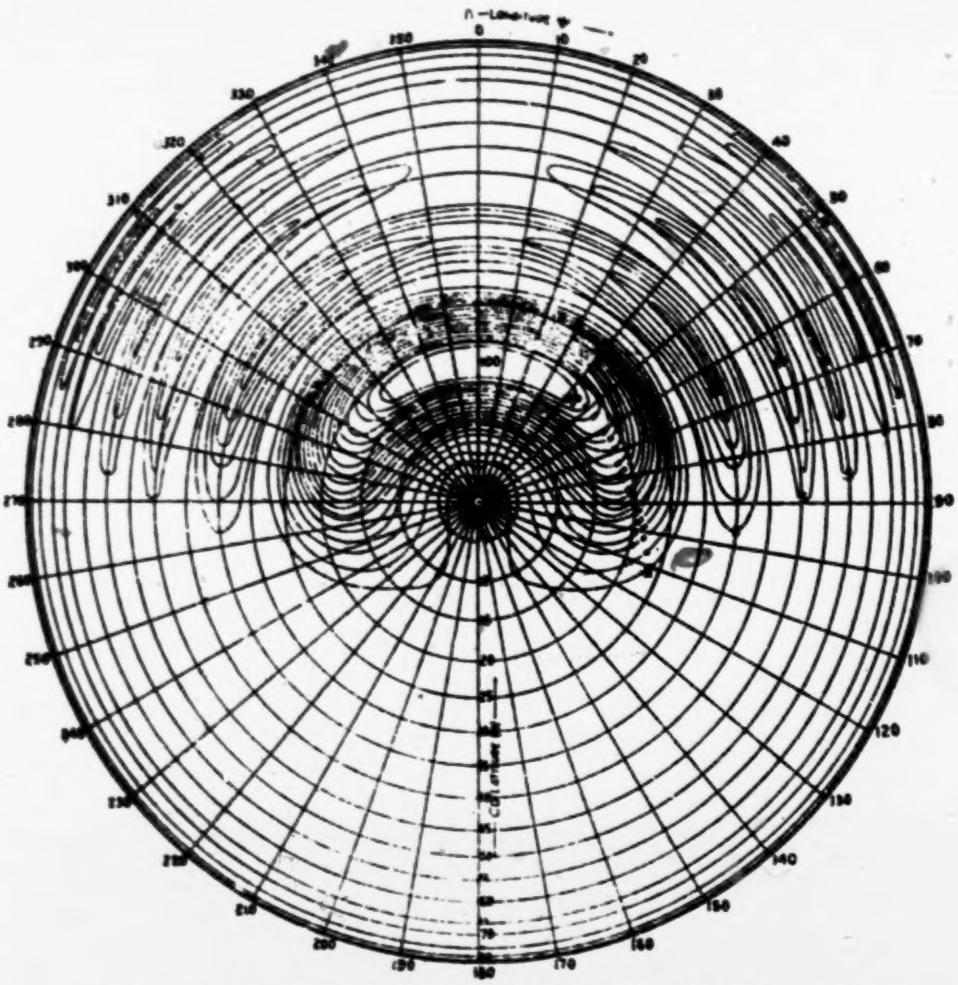


Fig. 32—This map is a projection of front half of imaginary sphere with one-bay vertical harmonic wire projector in the center.

Fig. 33 that the beam from two bays of the Model B antenna is remarkably like that of a search light.

(e) *Method of Calculating Directive Characteristics*

Consider two similar parallel wires spaced in any manner and let S be the line connecting the centers of these wires. (Fig. 34). The field intensity at any point in space is the instantaneous sum of the two components due to the wires. Let the wire pair be at the center of an

imaginary sphere whose radius is so great that lines from any point P on the surface of the sphere to any points on the radiating wires may be considered parallel. We can then neglect the effect of differences in distance upon the amplitudes and need only consider the phase. Let us take the line midway between the wires as our polar axis and measure

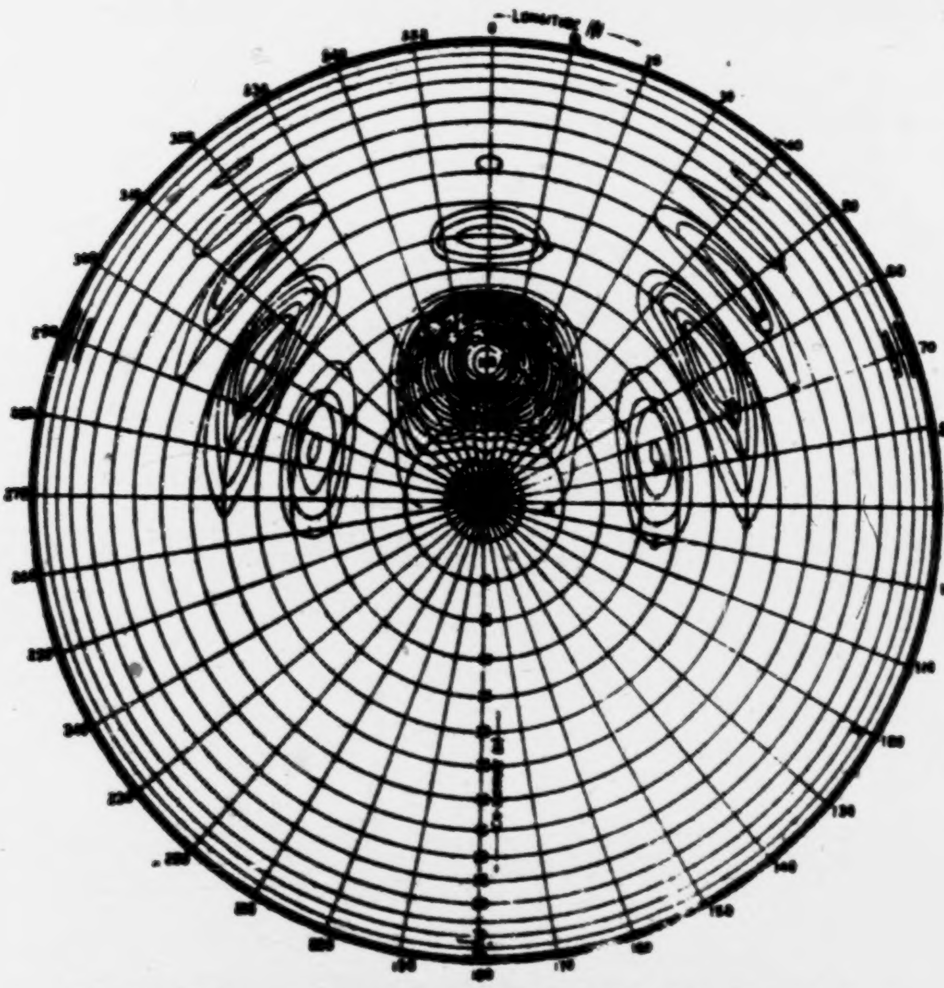


Fig. 33—This map is a projection of front half of imaginary sphere with two-bay vertical harmonic wire projector in the center.

positions of the point P in terms of the colatitude angle θ and the longitude angle ϕ using the intersection of the plane of the wires with the surface of the sphere as the zero meridian.

At a great distance we can consider the field components from the wires as originating at their centers. Now the difference in the distances of travel of the two components is the projection Δd of the line S upon the radius vector r to P. The difference in time of travel, Δt

must then be: $\Delta t = \Delta d/c$ where c is the velocity of light. The corresponding phase angle is then:

$$\gamma = 2\pi f \frac{\Delta d}{c} = 2\pi \frac{\Delta d}{\lambda} \tag{36}$$

where λ is the wavelength, and the wave from b leads the wave from a by this phase angle, provided the currents are in phase in the two wires. Suppose the current in b lags the current in a oy the phase angle ε. The total phase angle between the two field components is then:

$$\psi = \gamma - \varepsilon \tag{37}$$

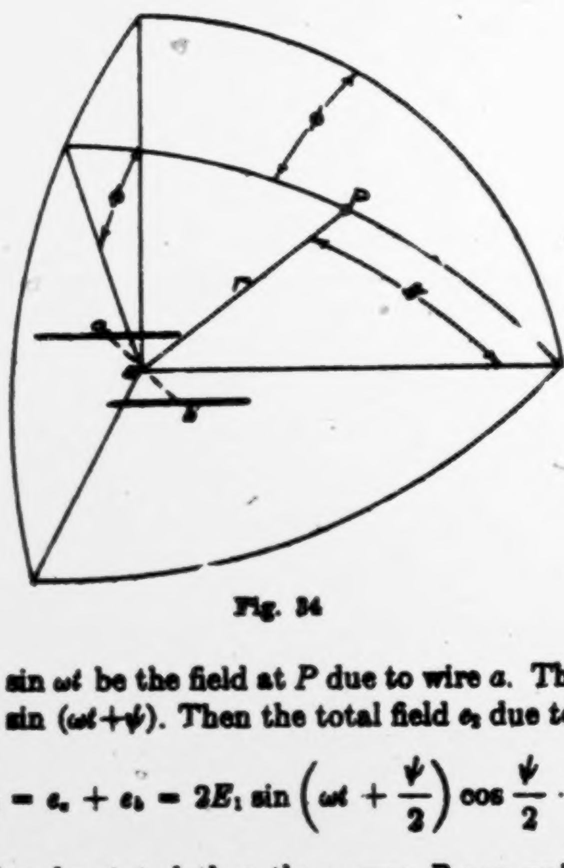


Fig. 34

Let $e_a = E_1 \sin \omega t$ be the field at P due to wire a. Then that due to wire b is $e_b = E_1 \sin(\omega t + \psi)$. Then the total field e_t due to both is:

$$e_t = e_a + e_b = 2E_1 \sin\left(\omega t + \frac{\psi}{2}\right) \cos \frac{\psi}{2} \cdot \tag{38}$$

We have already stated that the power P per unit area flowing through the surface of the sphere is $(c/4\pi)e^2$. We are interested in the time average of P which we shall designate as $\bar{P}$ and, to save words, shall simply call it "power." Since the time average of $\sin^2(\omega t + \psi)$ is one-half regardless of the phase angle ψ,

$$\bar{P} = \frac{c}{8\pi} E^2. \tag{39}$$

Hence for the pair:

$$\bar{P}_2 = \frac{c}{8\pi} 4E_1^2 \cos^2 \frac{\psi_1}{2} \tag{40}$$

$$= 4\bar{P}_1 \cos^2 \frac{\psi_1}{2} = 2\bar{P}_1(1 + \cos \psi_1) \tag{41}$$

where $\bar{P}_1$ is the power for one wire alone in space.

We can consider this pair as a unit and combine it with a second identical pair, spaced from the first in any desired manner, by the same procedure just outlined. If ψ_2 is the total phase angle between the field components, as determined by the spacing between centers of the pairs and the phase relations of the currents in the wires, the power $\bar{P}_4$ for the four is:

$$\bar{P}_4 = 4\bar{P}_2 \cos^2 \frac{\psi_2}{2} = 16\bar{P}_1 \cos^2 \frac{\psi_1}{2} \cos^2 \frac{\psi_2}{2}. \tag{42}$$

We can again combine this unit of four wires with a second similar unit spaced in any desired manner. If ψ_3 is the phase angle between the field components due to each of these sets of four wires, we obtain for the total power due to the complete system of eight wires:

$$\bar{P}_8 = 4\bar{P}_4 \cos^2 \frac{\psi_3}{2} = 64\bar{P}_1 \cos^2 \frac{\psi_1}{2} \cos^2 \frac{\psi_2}{2} \cos^2 \frac{\psi_3}{2} \tag{43}$$

We have shown in the discussion of single wires that the power for one wire is:

$$\bar{P} = \frac{I^2}{r^2 c} \frac{\sin^2\left(\frac{n\pi}{2} \cos \theta\right)}{\sin \theta} \tag{44}$$

when the length is an even multiple of a half wave and

$$\bar{P} = \frac{I^2}{r^2 c} \frac{\cos^2\left(\frac{n\pi}{2} \cos \theta\right)}{\sin \theta} \tag{45}$$

when the length is an odd multiple of a half wave.

In order to determine the power in any direction (θ, ϕ) it is now only necessary to determine the phase angles in terms of the coordinates (θ, ϕ) for substitution in the above formulas. We shall first consider the pair eight waves long forming the antenna proper. It is apparent from the geometry of the arrangement shown in Fig. 29 that

the length of the spacing line S is, $S=\lambda/2 \sin 35$ degrees $=0.872\lambda$. The line S makes an angle of $(90-17.5)$ degrees or 1.265 radians with the polar axis. Therefore, in the plane of the wires, where $\phi=0$ the projection Δd of the line S on the radius vector r is:

$$\Delta d = S \cos (1.265 - \theta) = 0.872 \cos (1.265 - \theta) \tag{46}$$

but for the general case of any direction (θ, ϕ) the projection is:

$$\begin{aligned}\Delta d &= 0.872[\cos 1.265 \cos \theta + \sin 1.265 \sin \theta \cos \phi]\lambda \\ &= 0.872[0.954 \cos \theta + 0.3005 \sin \theta \cos \phi]\lambda.\end{aligned} \tag{47}$$

Hence the phase angle γ due to the spacing becomes:

$$\gamma = 2\pi \frac{\Delta d}{\lambda} = 2\pi \cdot 0.872[0.954 \cos \theta + 0.3005 \sin \theta \cos \phi] \tag{48}$$

and, since the currents in the two wires are in phase opposition, the total phase angle is:

$$\psi = \pi - 2\pi \cdot 0.872[0.954 \cos \theta + 0.3005 \sin \theta \cos \phi]. \tag{49}$$

The spacing of the reflector pair from the antenna pair is one-half S and along the same line as S, and the two pairs are fed in quarter-phase relation. Therefore, the total phase angle is one-half that for a single pair or:

$$\psi_2 = \frac{\psi_1}{2}.$$

For the case of two sections of Model B antenna spaced apart by a distance x the projection of the spacing line x on the radius vector is:

$$\Delta d = x \sin \theta \sin \phi \tag{50}$$

and since the two sections are fed in phase, the phase angle is:

$$\psi_3 = 2\pi \frac{x}{\lambda} \sin \theta \sin \phi. \tag{51}$$

The complete expression for the power flow in any direction from a two-section vertical model system having a spacing x between sections is:

$$\begin{aligned}P_s = \frac{I^2 \sin^2 (8\pi \cos \theta)}{r^2 c \sin \theta} &\cos^2\left[\frac{\pi}{2} - 0.831\pi \cos \theta - 0.262\pi \sin \theta \cos \phi\right] \\ &\cdot \cos^2\left[\frac{\pi}{4} - 0.4155\pi \cos \theta - 0.131\pi \sin \theta \cos \phi\right] \\ &\cdot \cos^2\left[\pi \frac{x}{\lambda} \sin \theta \sin \phi\right].\end{aligned} \tag{52}$$

According to the definition which has been given the directivity is

$$D = \frac{\bar{P}_{max}}{\frac{1}{4\pi}\cdot W} \tag{53}$$

where W is the total power radiated. Since all the power radiated must flow through the surface of the imaginary sphere which we have been considering, the total power W must be the surface integral of P over the sphere. Hence,

$$\begin{aligned} W &= \iint_S \bar{P}dS \\ &= \int_0^{2\pi}\int_0^{\pi} \bar{P}r^2 \sin\theta d\theta d\phi \end{aligned} \tag{54}$$

since the element of surface dS on the sphere is $dS = r^2 \sin\theta d\theta d\phi$.

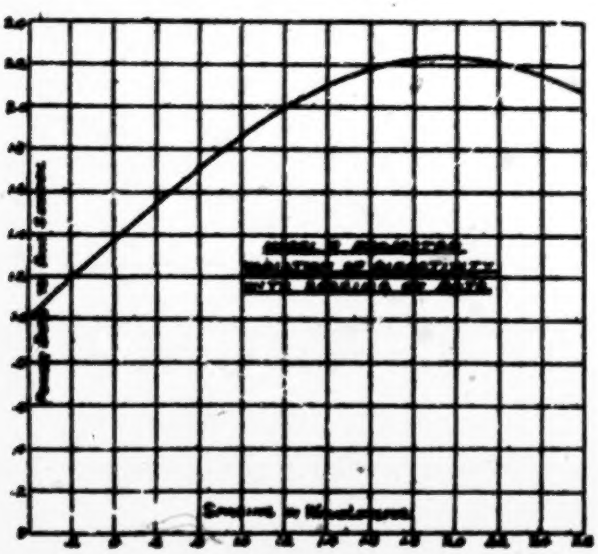


Fig. 35

Due to the extreme complexity of the expression for P (52) this integral cannot be evaluated in terms of elementary functions. Being a double integral mechanical integration involves the plotting of a number of curves. To determine the best spacing for the broadsiding of two sections, it is necessary to repeat the process of evaluation for several values of X. If, by performing one integration, the expression is reduced to a single integral, the labor is greatly reduced, it being necessary to plot only one curve for each condition. This operation has been done with the aid of Bessel's functions.

It can be proved that two sections of any type of radiating system will give an improvement of 2 to 1 in directivity over a single section if they are spaced apart a very great distance. The improvement ratio is an oscillating function of the spacing. It rises from 1 for zero spacing to a value somewhat greater than 2 at some particular spacing, depending upon the characteristics of the single section. As the spacing is further increased the ratio oscillates about a value of 2. For the Model B antenna the first maximum is obtained with a spacing of two wavelengths. Fig. 35 shows the way in which the power varies with the spacing.

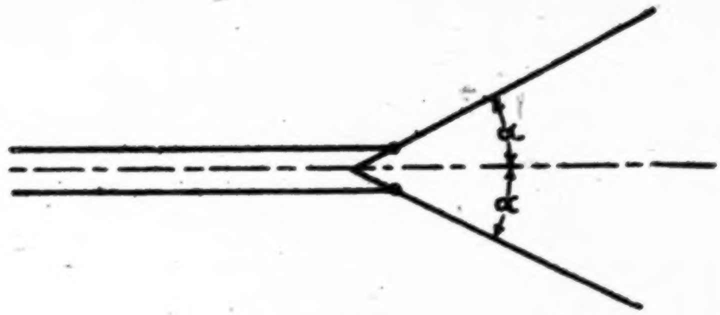


Fig. 36

The theoretical directivity for one section alone was computed as 26.3 and for a two-section system with 2λ spacing as 57.2. The corresponding ratios to a half-wave dipole are 16 and 35.0.

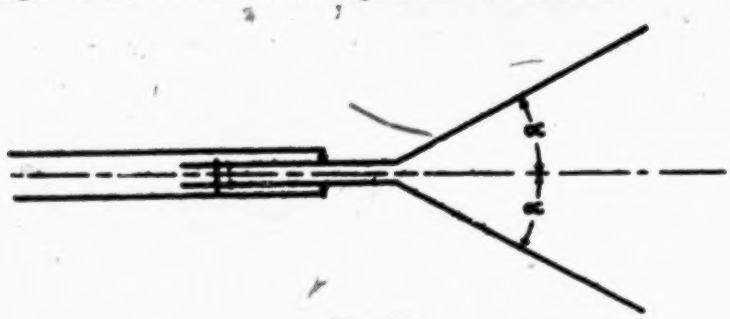


Fig. 37

The Model D Antenna

(a) *Description of System*

The fundamental radiating unit of the Model D antenna is a wire, having a length several times the wavelength used and which is partially folded upon itself from the center as shown in Fig. 36. The energy is fed from a transmission line in a manner similar to that in common use with half-wave dipoles.

For convenience in making adjustments, the modified arrangement shown in Fig. 37 is actually used. The correct angle (2α) between the wires depends upon their length in terms of wavelength.

Fig. 38 is a schematic diagram of a complete section of this system

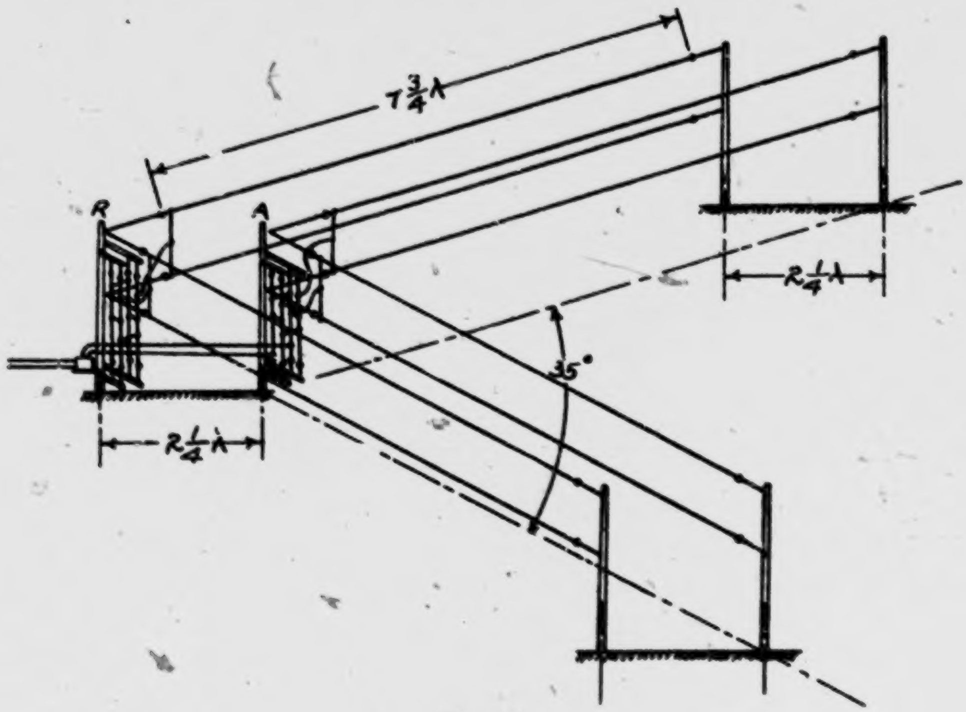


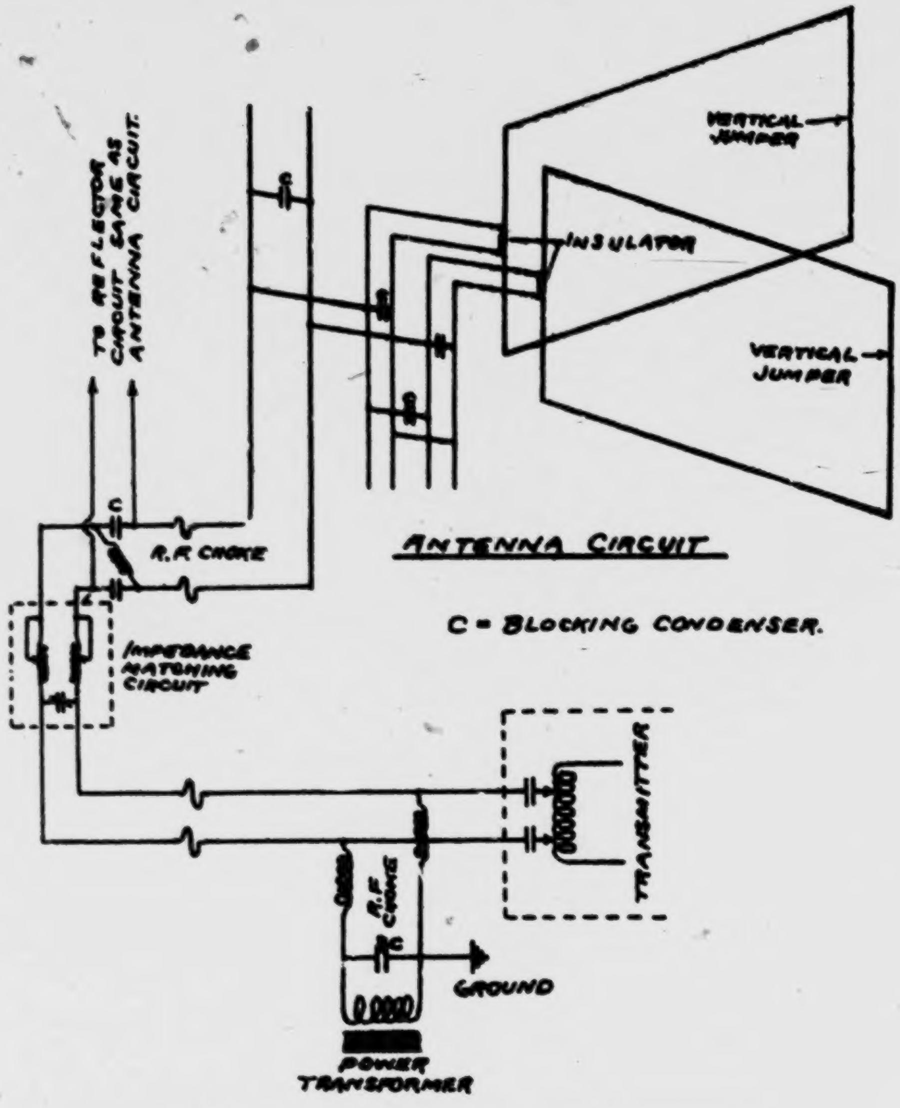
Fig. 38

as used for transmission with wavelengths in the vicinity of 17 meters. One section consists of two pairs of *V* units, *A* and *R*. Each pair consists of two units spaced one above the other at a distance of approxi-

Fig. 39

mately one-half wavelength. The units are fed in phase. The two pairs, *A* and *R*, are separated by a distance of 2 1/4 wavelengths along the center line, and pair *A* is fed in quarter-phase relation, either leading or lagging, with respect to *R*, depending upon whether transmission is to

be in the direction *A-R* or the direction *R-A*. With the connections as shown in the sketch transmission is in the direction *R-A*. To reverse the direction it is necessary only to make a transposition in the wires of the transmission line between *A* and *R*.



SCHEMATIC DIAGRAM SLEET MELTING CIRCUIT FOR MODEL "D" PROJECTOR

Fig. 40

In Fig. 39 is shown a schematic plan view of a two section system which takes the shape of a *W*. It is seen that a single section requires six supporting structures and each additional section four additional supports.

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This antenna is readily adapted for sleet melting. An arrangement whereby sleet can be melted from both the antenna and its transmission line at one time and without interruption to service is shown in Fig. 40. Radiation from the vertical jumper is negligible due to the fact that the current flow is from both ends toward the center of each jumper.

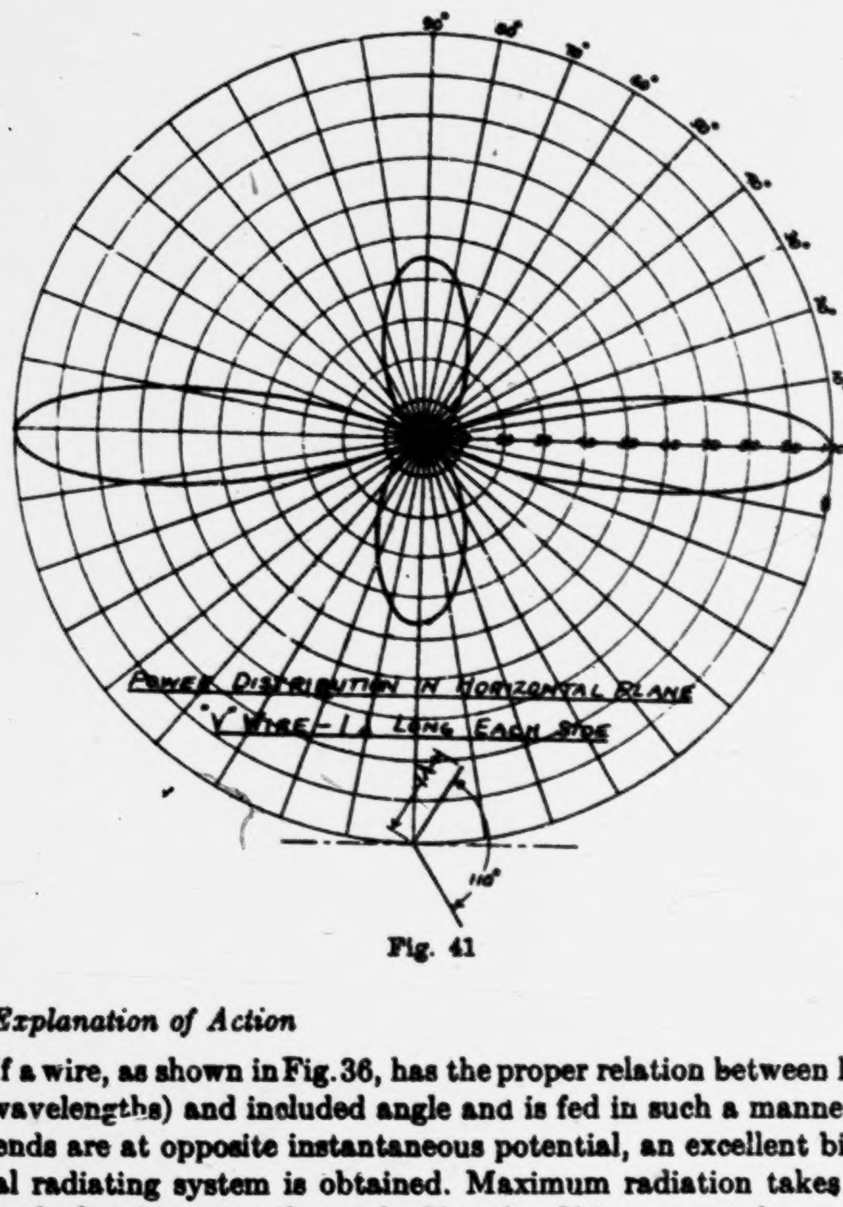

Fig. 41

(*b*) ***Explanation of Action***

If a wire, as shown in Fig. 36, has the proper relation between length (in wavelengths) and included angle and is fed in such a manner that the ends are at opposite instantaneous potential, an excellent bidirectional radiating system is obtained. Maximum radiation takes place along the line bisecting the angle. If such a V is connected to a transmission line in the manner already shown in Fig. 37, the correct potential relations will result.

Fig. 41 is a polar diagram showing the power distribution for a V

wire, having sides equal to one wave, in the plane of the wires. Fig. 42 is a similar diagram in a plane at right angles to the plane of the wires, which bisects the angle between them. For the sake of simplicity we shall henceforth call these two planes the horizontal plane and the vertical plane respectively. Figs. 43 and 44 are polar diagrams showing distributions of power for a V wire whose sides are each eight waves long.

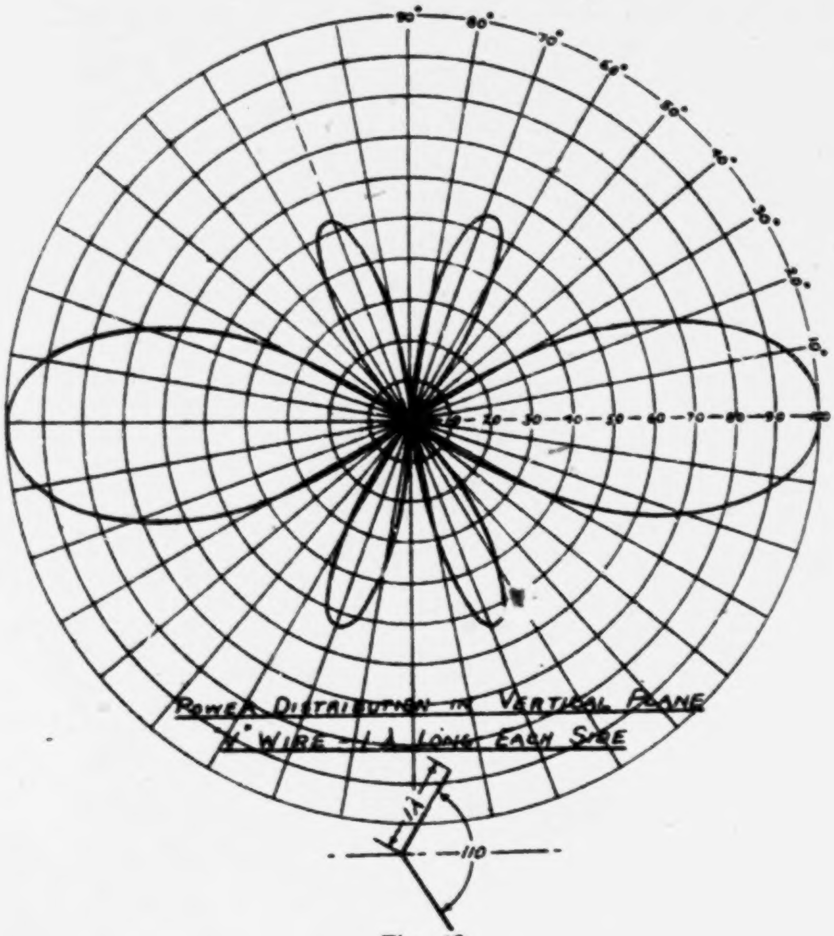

Fig. 42

The power distribution from a V wire can be considered as the effect resulting from the superposition of the radiated field waves from each side of the V. In Fig. 17 were shown a number of polar diagrams of relative power distribution for linear radiators of various lengths. In all cases the direction angle is shown with respect to the wire itself as the axis of reference. If we form a V from two such wires, making the included angle equal to twice the direction angle of the largest lobe, the two component field waves will add in phase along the center line and

maximum radiation will take place in the two directions along this line. In other directions in the horizontal plane the two components more or less cancel each other by wave interference. In directions at high angles to the horizon we have further reduction in intensities due to the non-parallel directions of the component field vectors. Fig. 45 shows in a qualitative way the manner in which the diagrams for the two wires forming the sides of the V combine to form the resultant pattern.

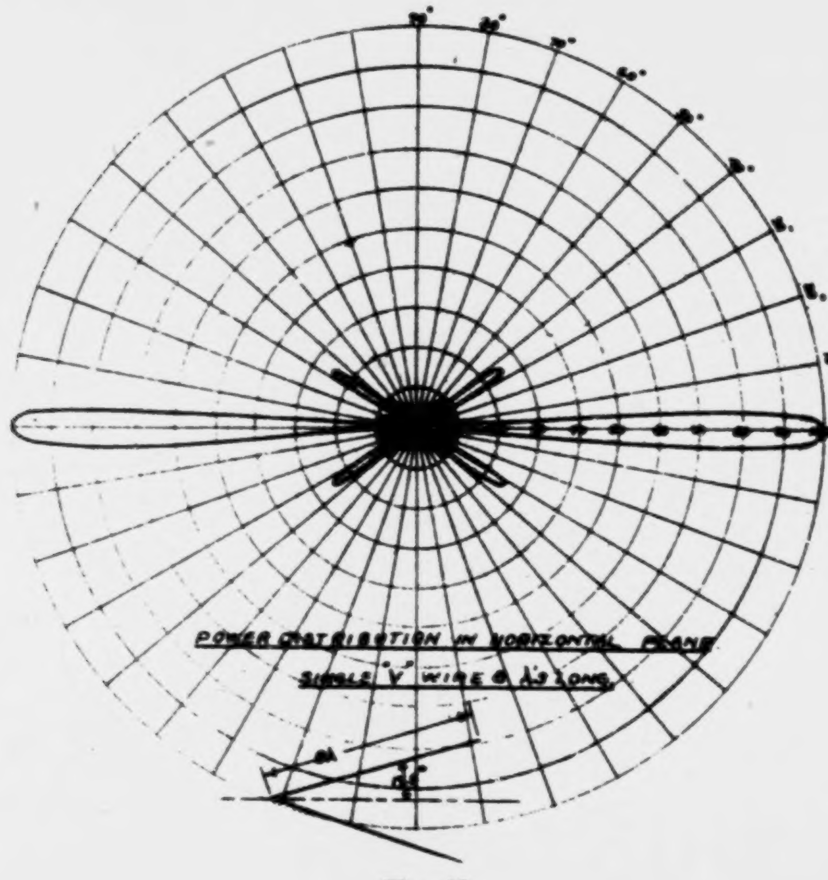

Fig. 45

Fig. 46 is a contour map of the power distribution from a V unit of sides equal to eight wavelengths. This shows only half the directive characteristic. The other half is identical with that shown.

Although the radiation at high angles is too low to show on the contour map, it is distributed over a large portion of the area of the sphere and therefore represents an appreciable portion of the total power. By placing a second V unit above or below the first at a distance of a half wavelength or more, and feeding it cophasially, the high angle radiation is reduced. As previously explained, a unidirec-

tional characteristic is obtained by using two radiator systems in the usual space and phase quadrature relation.

Fig. 47 is a contour map showing the power distribution on an imaginary sphere enclosing a complete antenna section. The antenna is considered as being in space far removed from ground. In the actual case the effect of ground must be considered.

The effect of ground upon a horizontally polarized wave is such as

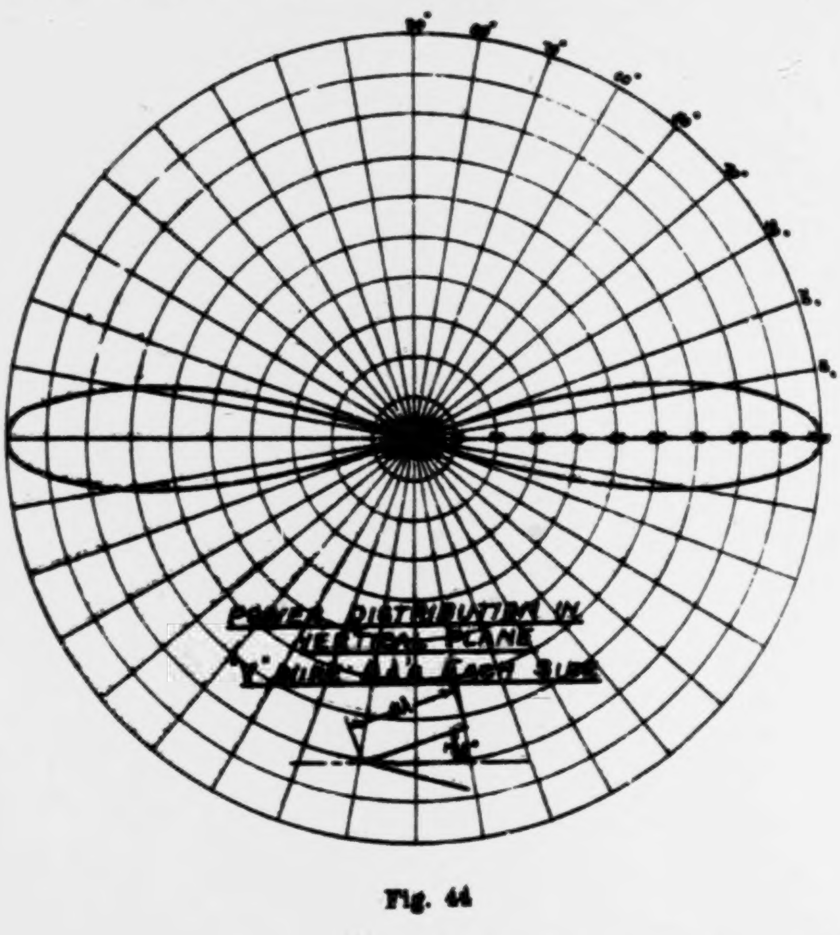

Fig. 44

to cancel radiation at zero angle to the horizon. Fig. 48 is a polar diagram showing the power distribution in the vertical plane when the antenna is located over a perfectly conducting ground and over sandy ground such as at Rocky Point. It is seen that there is little difference in the result in the two cases. The contour map, Fig. 49, shows the power distribution for a one-section antenna located over perfect ground. A comparison of this figure with Fig. 47 shows the effect of ground. Figs. 50 and 51 are contour maps, taking into account the effect of ground for two and three section systems respectively.

(c) *Theory*

1. The Folded Wire

Before considering the theory of the folded wire radiating system

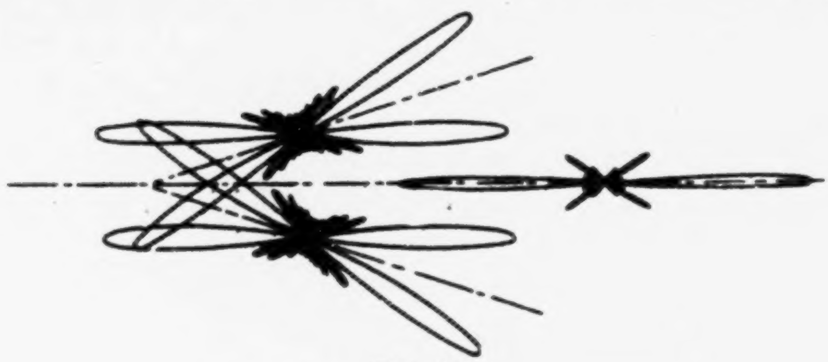

Fig. 45

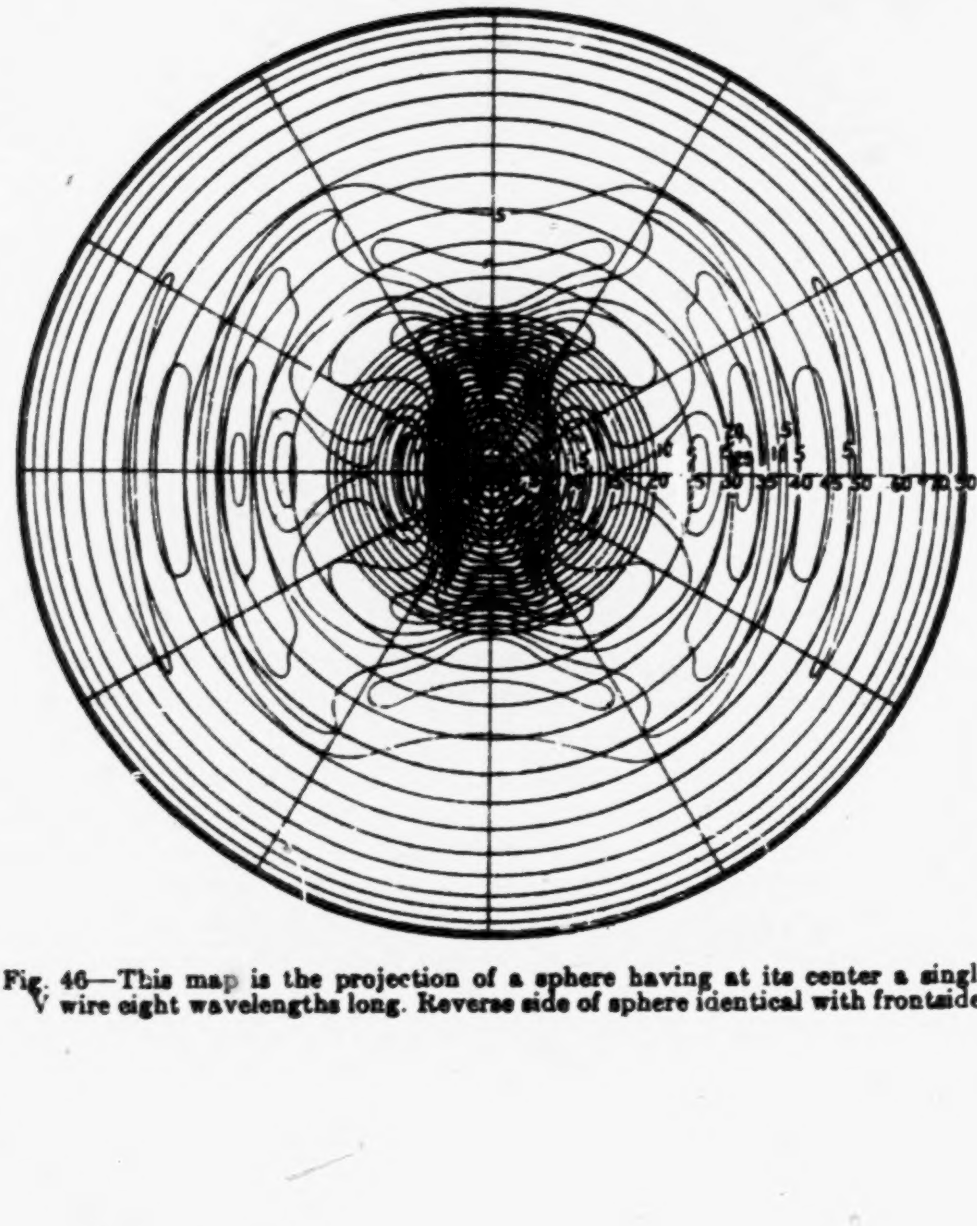

Fig. 46—This map is the projection of a sphere having at its center a single V wire eight wavelengths long. Reverse side of sphere identical with frontside.

we shall discuss certain principles in regard to radiated fields. We have not yet stressed the fact that electric and magnetic field intensities are vector quantities.

At a great distance from a linear radiator the direction of the electric field is at right angles to the radius vector and lies along the meridian line of an imaginary sphere having as its polar axis the axis of the

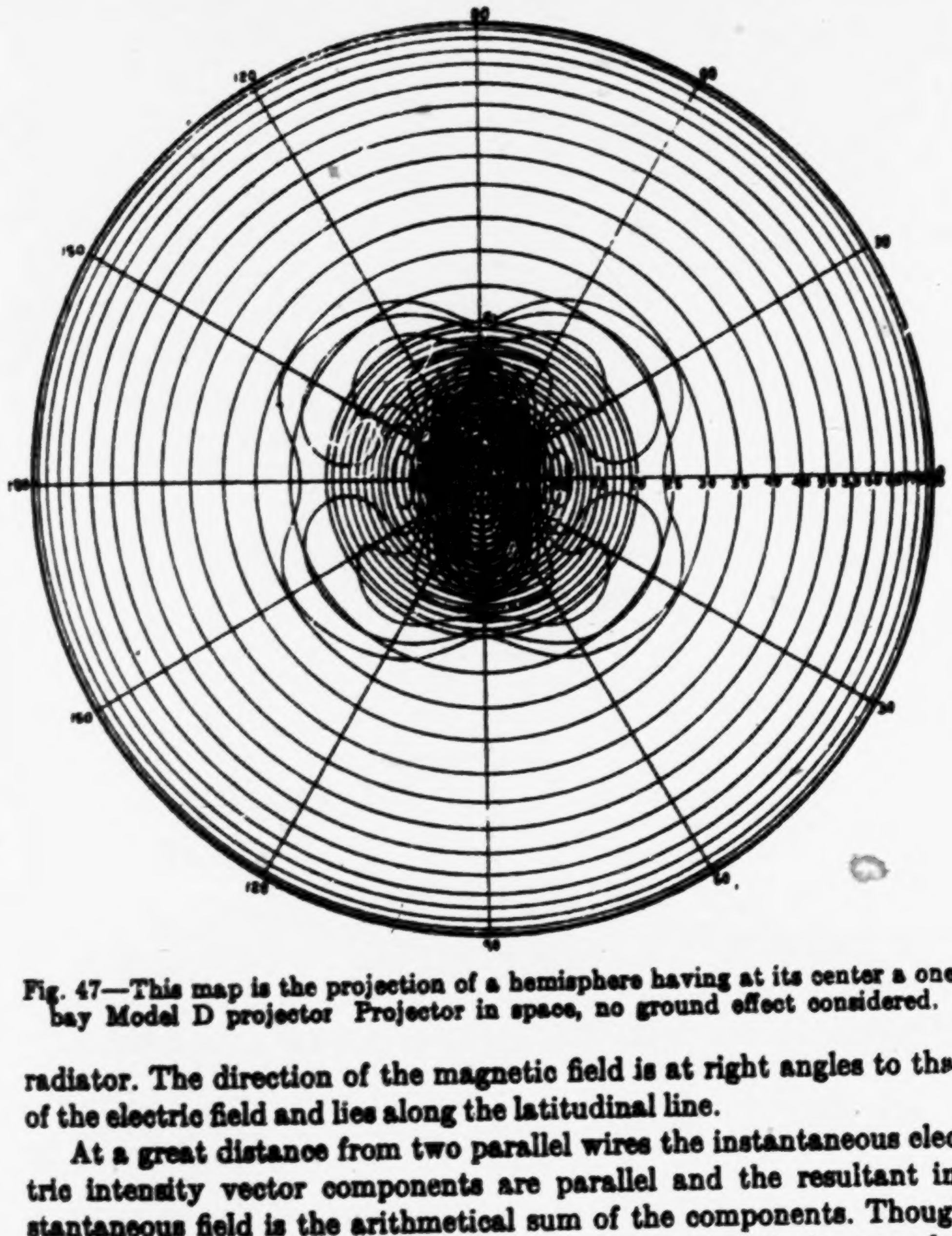

Fig. 47—This map is the projection of a hemisphere having at its center a one bay Model D projector Projector in space, no ground effect considered.

radiator. The direction of the magnetic field is at right angles to that of the electric field and lies along the latitudinal line.

At a great distance from two parallel wires the instantaneous electric intensity vector components are parallel and the resultant instantaneous field is the arithmetical sum of the components. Though the currents in the two radiators may be in phase there is, in general, a phase difference between the component field waves at the point of

reference due to the difference in time taken to travel the unequal distances to a distant point. Although we may, in this case, obtain the effective value of the resultant field by vectorial addition of the components it should be clearly understood that we are not adding true vectors but are simply making use of the principle that sine waves may be added vectorially. The distinction between a true vector quantity such as electric field intensity and the representation of a sinusoidal function of time, such as a current, by a vector is essential

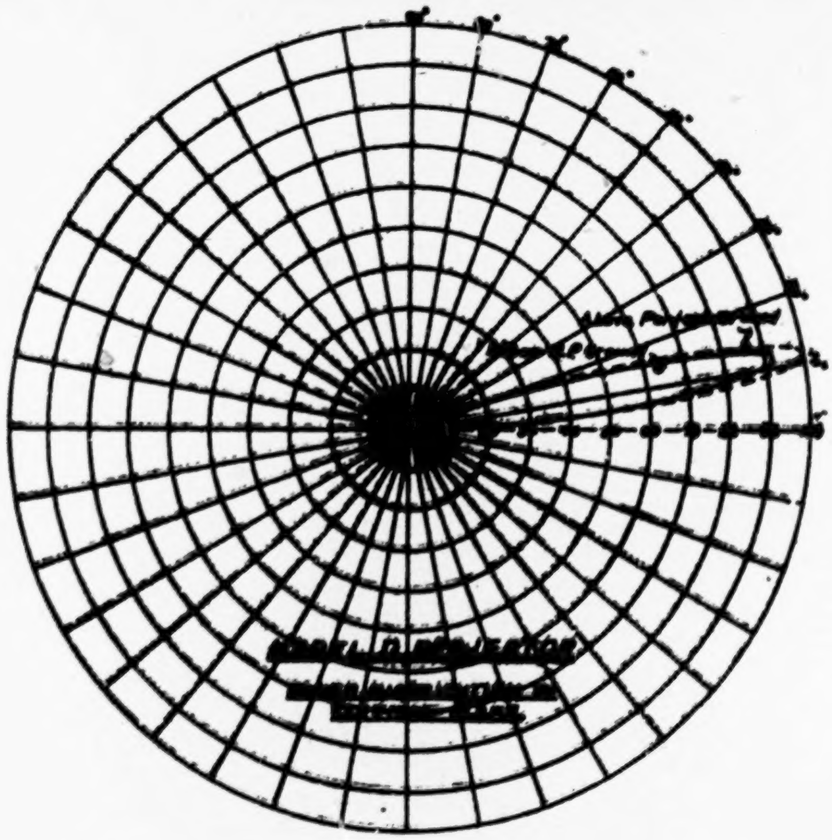

Fig. 46

to a clear understanding of the discussion to follow. The use of vectors to represent sine waves is avoided throughout this discussion in order to reduce the possibility of confusion to a minimum.

In the case where two radiators are not parallel the vector field components are in general not parallel and the resultant field is the instantaneous vector sum. In general the components differ in amplitude, phase, and direction and the terminus of the resultant vector describes an elipse during the period of each cycle. This condition is called elliptical polarization. Circular and plane polarization then be-

come special cases of the more general elliptical polarization. Fig. 52 is a vector diagram for two sinusoidal vectors having an amplitude ratio of 2:1, differing in phase by an angle of 45 degrees, and in direction by an angle of 60 degrees. Fig. 53 shows the variation of the power for this case.

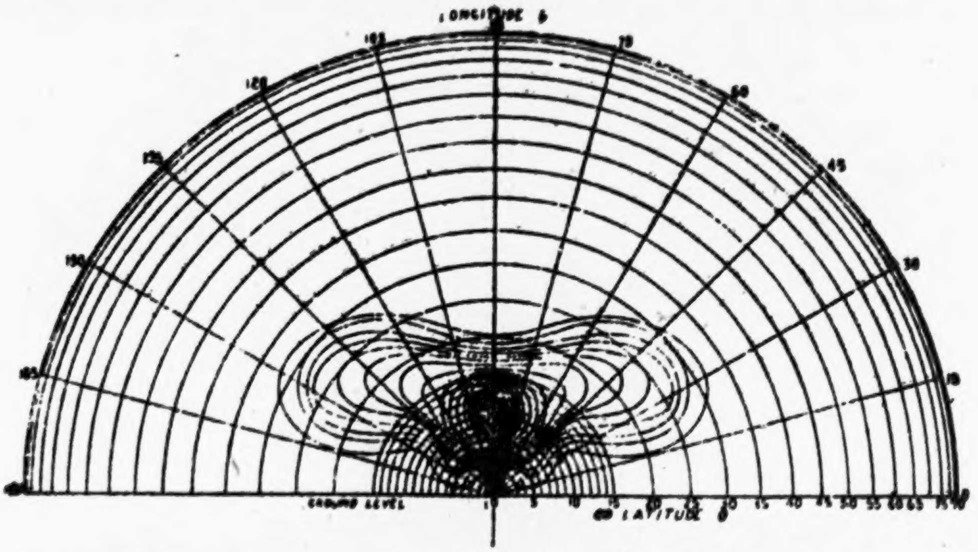

Fig. 49—This map is the projection of the upper front quadrant of an imaginary sphere having at its center a one-bay Model D projector. Projector above perfect ground.

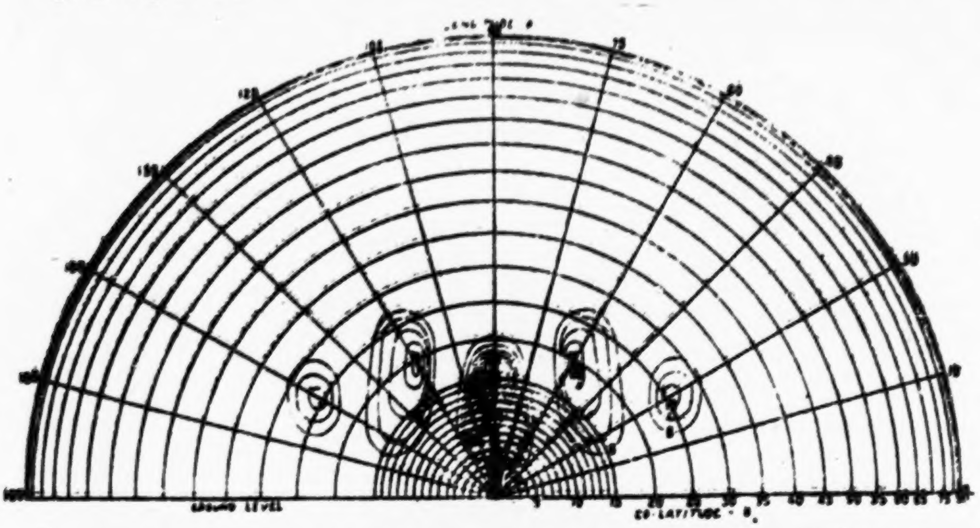

Fig. 50—This map is the projection of an imaginary sphere having at its center a two-bay Model D projector above a perfect ground.

We shall need expressions for the resultant field and the average power for the general case of elliptical polarization. We shall from now on designate a vector electric intensity by e and the magnitude of e

by e, the vector amplitude by $\boldsymbol{E}$ and the magnitude of the amplitude by E. It follows that:

$$e = E \sin(\omega t + \beta).$$

Assume that we have an electric intensity e which is the resultant

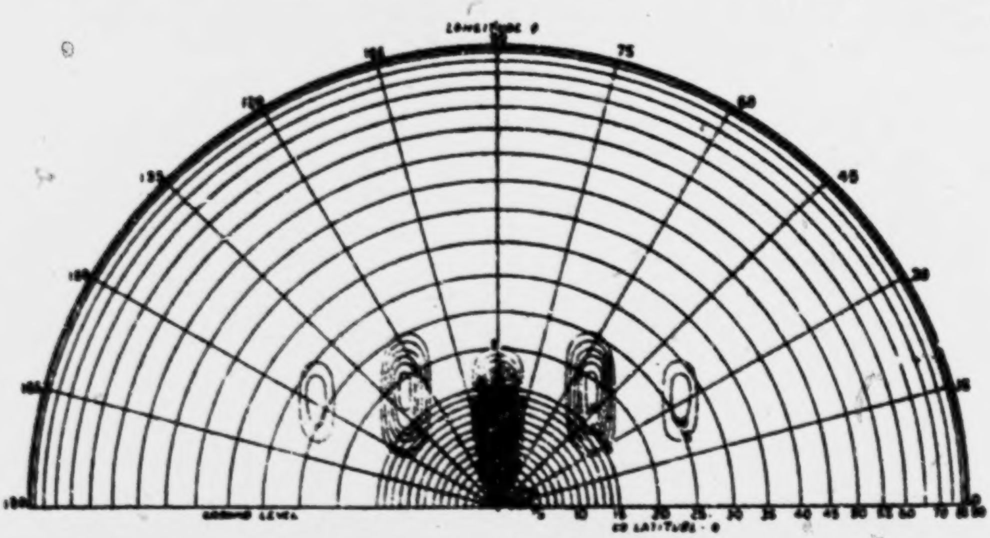

Fig. 51—This map is the projection of an imaginary sphere having at its center a three-bay Model D projector above a perfect ground.

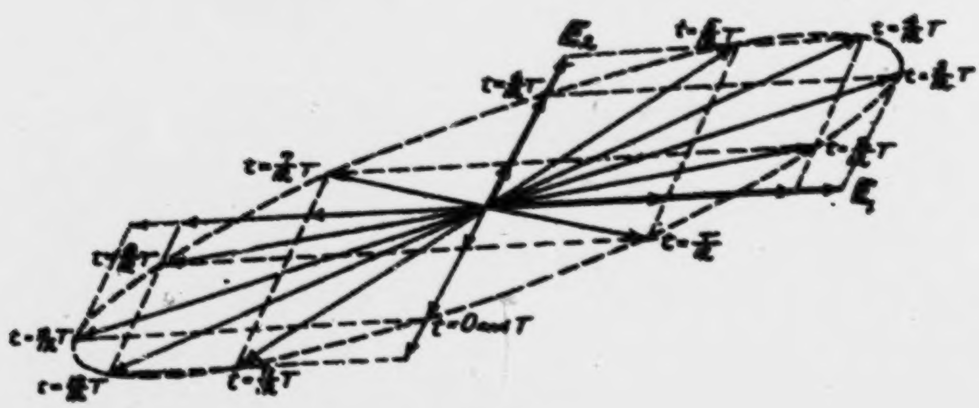

Fig. 52

of two component intensities e_a and e_b. Let these components differ in direction by the angle γ and in phase by the angle ψ. Then:

$$e_a = E_a \sin \omega t \text{ and } e_b = E_b \sin[\omega t + \psi] \tag{55}$$

and,

$$e = e_a + e_b = E_a \sin \omega t + E_b \sin[\omega t + \psi]. \tag{56}$$

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For the magnitude of the resultant intensity we obtain, by solving the vector triangle:

$$e = \sqrt{e_a^2 + e_b^2 + 2e_ae_b \cos\gamma}$$
$$= \sqrt{E_a^2 \sin^2 \omega t + E_b^2 \sin^2 (\omega t + \psi) + 2E_aE_b \sin \omega t \sin (\omega t + \psi) \cos \gamma} \quad (57)$$

The power per unit area (Poynting's vector) becomes:

$$P = \frac{c}{4\pi}e^2 = \frac{c}{4\pi}[E_a^2 \sin^2 \omega t + E_b^2 \sin^2 (\omega t + \psi) + 2E_aE_b \sin \omega t \sin (\omega t + \psi) \cos \gamma] \quad (58)$$

Fig. 53

and the time average of the power per unit area becomes:

$$\bar{P} = \frac{1}{2\pi}\int_0^{2\pi} P d(\omega t) = \frac{c}{8\pi}(E_a^2 + E_b^2 + 2E_aE_b \cos\gamma \cos\psi). \quad (59)$$

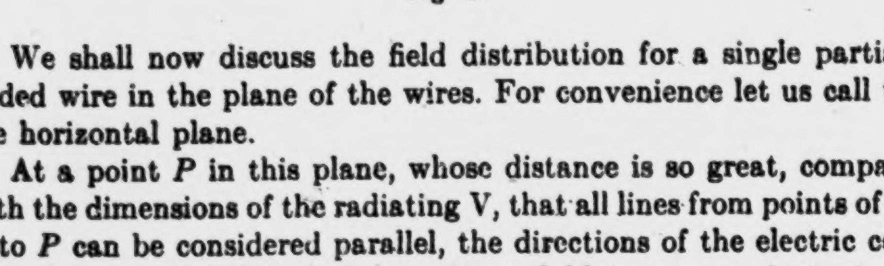

Fig. 54

We shall now discuss the field distribution for a single partially folded wire in the plane of the wires. For convenience let us call this the horizontal plane.

At a point P in this plane, whose distance is so great, compared with the dimensions of the radiating V, that all lines from points of the V to P can be considered parallel, the directions of the electric components are parallel and the resultant field is, at any instant, the arithmetical sum of the components. The phase of the total field fron

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either wire is the same as the phase of the field from a small element at the center of the wire. Therefore, we may consider the resultant field at P to be due to the fields e_a and e_b from each wire originating at the center points a and b. In Fig. 54 let us take as reference time the time at which a wave from O arrives at P. The wave from a will take Δt seconds longer and the wave from b Δt seconds less than a wave from O where $\Delta t = \Delta d/c$. From the geometry of the figure:

$$\Delta d = \frac{l}{2} \sin \alpha \sin \theta \tag{60}$$

where l is the length of the wire.

To save space we shall consider only the case where the sides of the V are an even number of half waves long.

From (10) we obtain for the two field components, after substituting $t+\Delta t$ and $t-\Delta t$ to take care of the differences in the time of travel to P:

$$e_a = \frac{2I \sin\left(\frac{n\pi}{2} \cos \theta_a\right)}{cr \sin \theta_a} \sin \omega(t - \Delta t) = E_a \sin \omega(t - \Delta t) \tag{61}$$

$$e_b = \frac{2I \sin\left(\frac{n\pi}{2} \cos \theta_b\right)}{cr_0 \sin \theta_a} \sin \omega(t + \Delta t) = E_b \sin \omega(t + \Delta t) \tag{62}$$

in which $\theta_a = \theta - \alpha$, $\theta_b = \theta + \alpha$, and $\Delta t = l/2c \sin \alpha \cos \theta$.

Since the currents in a and b are in opposite phase

$$e = e_a - e_b = \sqrt{E_a^2 + E_b^2 - 2E_aE_b \cos\left(2\pi \frac{l}{\lambda} \sin \alpha \sin \theta\right)} \sin(\omega t + \beta) \tag{63}$$

and the time average of the power per unit area becomes:

$$\mathbf{P} = \frac{c}{8\pi}\left[E_a^2 + E_b^2 - 2E_aE_b \cos\left(2\pi \frac{l}{\lambda} \sin \alpha \sin \theta\right)\right] \tag{64}$$

from which the relative values of the power distribution in the horizontal plane may be computed.

Throughout the remainder of this discussion we shall use the word "power" to indicate the time average of the power per unit area and designate this by $\mathbf{P}$.

In the plane at right angles to the plane of the wires and including the bisector, which, for convenience, is designated as the vertical plane, the distances to each wire are equal and the time difference of travel zero. However, in this plane, in proceeding from the horizontal to the vertical direction the angle between the directions of the component vectors changes from zero to $(\pi - 2\alpha)$. The two electric field vectors are equal and lie along the meridian lines of two concentric spheres, one having as its polar axis the axis of the wire a and the other the axis of wire b as shown in Fig. 55. If θ is the direction angle to the point P with reference to the bisector and θ_a and θ_b the angles to the wire axes, then

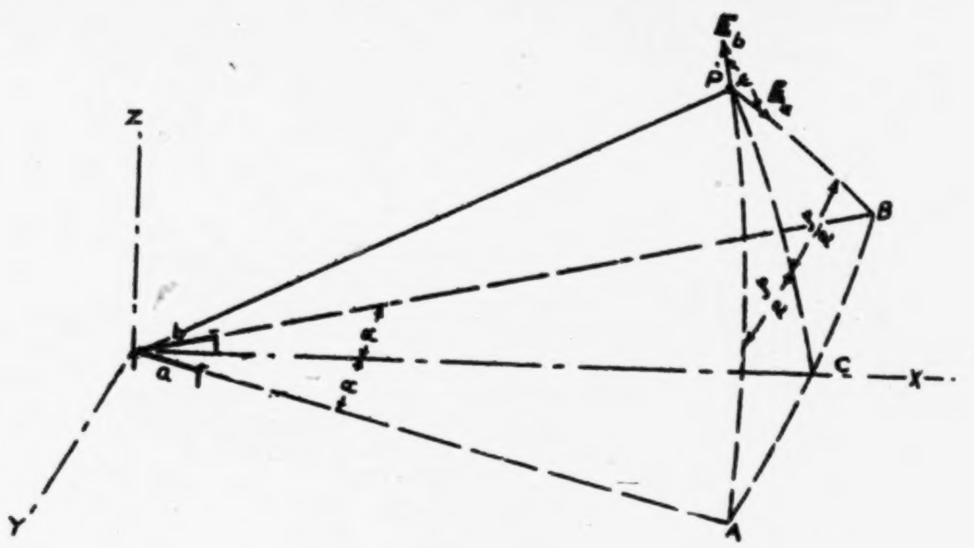


Fig. 55

$\theta_a = \theta_b$. θ_a and ζ are obtained by solving the right spherical triangle $A\,C\,P$, resulting in the relations

$$\cos\theta_a = \cos\theta\cos\alpha \tag{65}$$

$$\sin\frac{p}{2} = \frac{\sin\alpha}{\sin\theta_a} = \frac{\sin\alpha}{\sqrt{1-\cos^2\theta\cos^2\alpha}}\,. \tag{66}$$

The resultant intensity must be the vector sum of the components:

$$e = e_a + e_b$$

but,

$$e_a = e_b$$

therefore,

$$e = 2e_a\cos\frac{\gamma}{2} \tag{67}$$

where γ is the angle between the directions. However, since the wires are at opposite polarity, the angle

$$\gamma = \pi - \zeta \tag{68}$$

where ζ is the angle between the two meridians.
Hence,

$$\begin{aligned} e &= 2e_a \sin\frac{\zeta}{2} \\ &= \frac{4I}{cr}\sin\omega t\,\frac{\sin\left(\frac{n\pi}{2}\cos\frac{\theta_a}{2}\right)}{\sin\theta_a}\sin\frac{\zeta}{2} \end{aligned} \tag{69}$$

upon obtaining the value of e_a from (10).

Substituting (65) and (66) into (69) we obtain:

$$e = \frac{4}{cr}I\sin\omega t\,\frac{\sin\left(\frac{n\pi}{2}\cos\alpha\cos\theta\right)\sin\alpha}{1-\cos^2\theta\cos^2\alpha} \tag{70}$$

and the time average of the power is

$$\overline{P} = \left|\frac{c}{4\pi}\cdot e^2\right|_{ave} = \frac{2I^2\sin^2\left(\frac{n\pi}{2}\cos\alpha\,.\,\cos\theta\right)}{\pi cr\left[1-\cos^2\theta\cos^2\alpha\right]^2} \tag{71}$$

or,

$$\overline{P} \propto \frac{\sin^2\left(\frac{n\pi}{2}\cos\alpha\,.\,\cos\theta\right)}{\left[1-\cos^2\theta\cos^2\alpha\right]^2} \tag{72}$$

and from this proportionality can be calculated the relative power distribution in the vertical plane. The power distribution for V wires having sides one wave and eight waves long respectively have already been shown in Figs. 42 and 44.

In planes other than the two already considered, the field vector components differ in amplitude, direction and phase. We have already shown how this results in elliptical polarization and derived the formula for the power. In order to make use of the formula we must first determine the phase angle and the direction angle between the two vector components.

The phase angle between the wave from a and the wave from b is: $\psi = \omega\Delta t = \omega\Delta d/c$ where Δd is the projection of the line s, connecting the centers of the wires, upon the radius vector r. In spherical coördinates, (see Fig. 56.)

$$\Delta d = s \sin\theta \cos\phi \tag{73}$$

but,

$$s = l \sin\alpha$$

therefore,

$$\psi = 2\pi \frac{l}{\lambda} \sin\alpha \sin\theta \cos\phi. \tag{74}$$

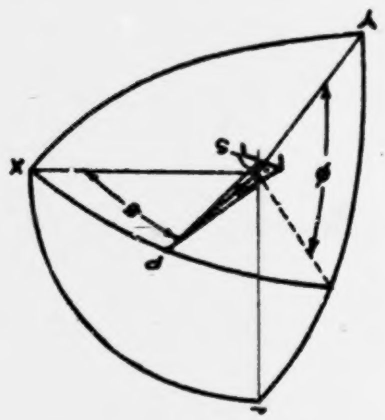


Fig. 56

The vector field components lie along the meridian lines of two superimposed spheres having as their polar axes continuations of the wires as shown in Fig. 57. The angle γ between the vectors is $\pi - \zeta$

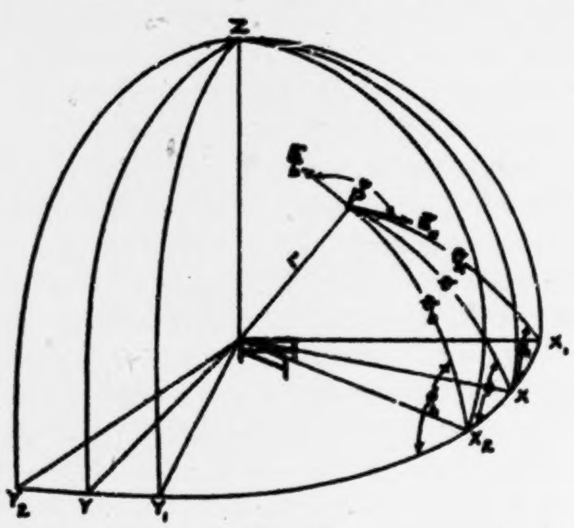


Fig. 57

where ζ is the angle between the meridians. To determine ζ in terms of the coördinates (θ, ϕ) it is necessary to solve the oblique spherical triangle X_1PX_2. We also need θ_a and θ_b in terms of θ and ϕ in order to determine the amplitudes of e_a and e_b.

By spherical trigonometry:

$$\cos\theta_a = \cos\theta\cos\alpha + \sin\theta\sin\alpha\cos\phi \tag{75}$$

$$\cos\theta_b = \cos\theta\cos\alpha - \sin\theta\sin\alpha\cos\phi \tag{76}$$

and,

$$\cos\frac{\zeta}{2} = \sqrt{\frac{\sin\left(\dfrac{\theta_a}{2}+\dfrac{\theta_b}{2}-\alpha\right)\sin\left(\dfrac{\theta_a}{2}+\dfrac{\theta_b}{2}+\alpha\right)}{\sin\theta_a\sin\theta_b}}. \tag{77}$$

Upon the substitution of $\pi-\zeta$ for γ in (64) we obtain:

$$\overline{P} = \frac{c}{8\pi}(E_a^2 + E_b^2 - 2E_aE_b\cos\zeta\cos\psi). \tag{78}$$

Having obtained θ_a and θ_b from (75) and (76) we can obtain E_a and E_b from (10), ψ from (74), and ζ from (77) which, upon substitution in (78), give us the power radiated in any direction (θ,ϕ). The contour map resulting from such calculations has been shown in Fig. 46.

2. The Complete Antenna Section

If we space two like linear radiators in any manner whatsoever, as long as their axes remain parallel, the field intensity at any point in space is $2e_1\cos\psi/2$ where ψ is the phase angle determined in the proper manner and e_1 the intensity due to one radiator alone. If $\overline{P}_1$ is the power due to one alone, the power due to both is $4\overline{P}_1\cos^2\psi/2$. We can combine any number of pairs of groups according to this law. In the system under discussion we have units resulting in elliptical polarization and we wish to investigate the laws for arrays of such units.

The intensity in an elliptically polarized wave can always be resolved into two harmonic components, one acting along the major axis and one along the minor. A similar case in mechanics is the motion of a pendulum when describing an elliptic orbit. Suppose we have two identical radiating systems in which flow equal currents and which are spaced in any manner whatever as long as the corresponding elements in the two systems remain parallel. Assume that at a point P at a great distance from the two systems we find the phase angle to be ψ, after taking proper account of time of travel and relative phase of currents. Let e_s be the intensity due to either system alone. Let its major and minor components be e_s' and e_s'', respectively, and E_s' and E_s'' the amplitudes of these components. The total field amplitude E' along the major axis is then:

$$E_a' = 2E_a' \cos\frac{\psi}{2} \tag{79}$$

and the total field amplitude E'' along the minor axis is:

$$E'' = 2E_a'' \cos\frac{\psi}{2} \tag{80}$$

The power due to the intensity along the major axis is:

$$\overline{P}' = \frac{c}{8\pi} 4E'^2 \cos^2\frac{\psi}{2} \tag{81}$$

and for the minor axis:

$$\overline{P}'' = \frac{c}{8\pi} 4E''^2 \cos^2\frac{\psi}{2} \tag{82}$$

and the total power is:

$$\overline{P} = \overline{P}' + \overline{P}'' = \frac{c}{8\pi} 4(E_a'^2 + E_a''^2) \cos\frac{\psi}{2} \tag{83}$$

but the power due to either system alone is

$$\overline{P}_a = \frac{c}{8\pi}(E_a^2 + E_a''^2) = \frac{c}{8\pi} E_a^2. \tag{84}$$

Therefore, by substitution the total power is

$$\overline{P} = 4\overline{P}_a \cos^2\frac{\psi}{2} \tag{85}$$

which is the same as if the two systems were radiating plane polarised waves. Therefore we can treat arrays of units radiating elliptically polarised waves in the same manner as arrays of simple oscillators.

If we place two identical radiating systems one above the other with a spacing s the phase angle between the two component field waves will be zero for directions in the horizontal plane ($\phi = 0$). At a point in any particular direction (θ, ϕ) in space the phase angle ψ between the components must be: $\psi = 2\pi\Delta d/\lambda$ where Δd is the projection of the vertical line s on the radius vector to the point P. In terms of the spherical coördinates θ. ϕ,

$$\Delta d = S \sin\theta \sin\phi. \tag{86}$$

If $\overline{P}_1$ is the power for one system alone then the power for the combination is:

$$\overline{P}_2 = 4\overline{P}_1 \cos^2\left(\frac{\pi S}{\lambda} \sin\theta \sin\phi\right) \tag{87}$$

from (85).

To obtain a unidirectional system we place a second pair (*b*) of V wires behind the first pair (*a*) a distance *q* equal to an odd number of quarter waves and feed system (*b*) leading (*a*) in phase by an angle $2\pi q/\lambda$. At a point *P* in any direction θ, ϕ, in space the difference in time of travel of the waves from *a* and *b* is $\Delta d/c$ where Δd is the projection of the horizontal line *q* upon the radius vector to *P*. Hence $\Delta d = q \cos\theta$ and the corresponding phase angle is $2\pi q/\lambda \cos\theta$. The total phase angle ψ is the difference between the phase angle due to the currents and the phase angle due to difference in time of travel. Hence

$$\psi = 2\pi \frac{q}{\lambda}(1 - \cos\theta) = \frac{4\pi q}{\lambda}\sin^2\frac{\theta}{2}\cdot \tag{88}$$

Upon substituting this value of the phase angle in (85) we obtain:

$$\overline{P}_{ab} = 4\overline{P}_a \cos^2\left(2\pi\frac{q}{\lambda}\sin^2\frac{\theta}{2}\right) \tag{89}$$

which becomes, after replacing $\overline{P}_a$ with its value in terms of $\overline{P}_1$ from (85):

$$\overline{P}_{ab} = 16\overline{P}_1 \cos^2\left(\frac{\pi S}{\lambda}\sin\theta\sin\phi\right)\cos^2\left(2\pi\frac{q}{\lambda}\sin^2\frac{\theta}{2}\right). \tag{90}$$

Knowing the value of $\overline{P}_1$ for the single V this equation enables us to determine the distribution through space for the complete antenna section. The resulting contour map has been shown in Fig. 47

So far we have considered the antenna system in space only, neglecting any effects due to ground. In most treatments of radiating systems the ground is assumed a perfect conductor in which case it acts as a perfect mirror. In most cases this assumption is not justified. For short wavelengths the ground acts much more like a perfect dielectric than a perfect conductor. At Rocky Point the soil is sand of extremely small conductivity and having a dielectric constant of approximately 9. In this case the conductivity may be neglected in determining the reflection.

It can be shown from electromagnetic theory that the coefficient of reflection for a wave polarized at right angles to the plane of incidence (horizontal polarization) is, for a pure dielectric, given by the formula:

$$K_h = \frac{\cos\delta - \sqrt{\epsilon - \sin^2\delta}}{\cos\delta + \sqrt{\epsilon - \sin^2\delta}} \tag{91}$$

where ϵ is the dielectric constant and δ the angle of incidence. $\delta = 90$ degrees $-\theta$ where θ is the angle to the horizontal.

When a wave is polarized in the plane of incidence the coefficient of reflection is:

$$K_i = \frac{\epsilon \cos \delta - \sqrt{\epsilon - \sin^2 \delta}}{\epsilon \cos \delta + \sqrt{\epsilon - \sin^2 \delta}}. \tag{92}$$

In the vertical plane including the line of maximum radiation, the wave from the system under discussion is horizontally polarized. At a point P at a great distance the field is the sum of the direct and reflected waves where proper account of the phase angle due to the greater distance of travel of the reflected wave is taken into account. From the geometry of Fig. 58 it is apparent that the reflected wave may

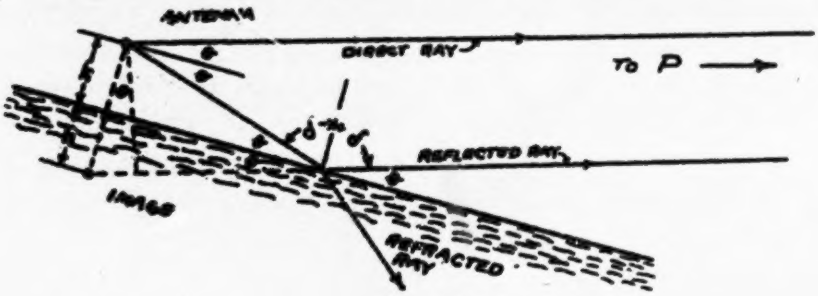


Fig. 58

be considered as originating at an image in which is flowing a current $K_h I$ where I is the current in the antenna. The phase angle between the direct and reflected waves is then:

$$\psi = 4\pi \frac{h}{\lambda} \sin \theta. \tag{93}$$

Adding the two waves we obtain for the power $\overline{P}_g$ when reflection from ground is taken into consideration:

$$\overline{P}_g = \overline{P}_o\left[1 + K_h^2 + 2K_h \cos\left(4\pi \frac{h}{\lambda} \sin \theta\right)\right] \tag{94}$$

where $\overline{P}_o$ is the power neglecting ground.

For the case of a perfect conducting ground the field at P is the sum of the fields due to the antenna and its negative image. The distributions of radiation in the vertical plane both for Rocky Point ground and a perfectly conducting ground have already been shown in Fig. 48. It is seen from this figure that, for this particular antenna system, the assumption of a perfect ground results in approximately the same distribution as that obtained for a dielectric. If the waves had been vertically polarized, the results would have been entirely different.

In vertical planes other than that which we have termed *the* vertical plane, the waves from this antenna are elliptically polarized. The treatment of the reflected wave from dielectric ground in such a case is extremely laborious since the components parallel and normal to the plane of incidence must be considered separately. For this reason together with the fact that in this case there is no great error, the contour map in Fig. 49 was made assuming perfectly conducting ground. An exact mathematical treatment would probably be little nearer the truth since, under actual conditions, there are many factors which are not exactly known.

By placing two complete sections side by side along a line at right angles to the direction of the beam, the concentration of radiated power in the desired direction is approximately doubled. The distribution of power is obtained by adding together the fields due to each section while taking proper account of the phase angle. If X is the length of the line between the apexes of the two sections, the phase angle is $2\pi X/\lambda$ times the projection of this line upon the radius vector in the direction under consideration. In our system of spherical coördinates, the phase angle is:

$$\psi = 2\pi \frac{x}{\lambda} \sin\theta \cos\phi \tag{95}$$

and, from (85), we obtain for the power from the two-section system:

$$\bar{P}_2 = 4\bar{P}_1 \cos^2\left(\pi \frac{x}{\lambda} \sin\theta \cos\phi\right) \tag{96}$$

where $\bar{P}_1$ is the power for one section alone.

To obtain the power for a four-section system we can combine two double-section systems. Then:

$$\bar{P}_4 = 16\bar{P}_1 \cos^2\left(\frac{\pi x}{\lambda} \sin\theta \cos\phi\right) \cos^2\left(2\pi \frac{x}{\lambda} \sin\theta \cos\phi\right). \tag{97}$$

For a three-section system the formula for power distribution is:

$$\bar{P}_3 = \bar{P}_1 \left[1 + 2\cos\left(2\pi \frac{x}{\lambda} \sin\theta \cos\phi\right)\right]^2. \tag{98}$$

Contour maps showing the distribution of power for one-, two-, and three-section systems at a mean height of one wavelength above perfect conducting ground has been shown in Figs. 49, 50, and 51.

Figs. 59 and 60 show the power distribution in a plane inclined at 10.5 degrees to the horizontal, the vertical angle of maximum radiation.

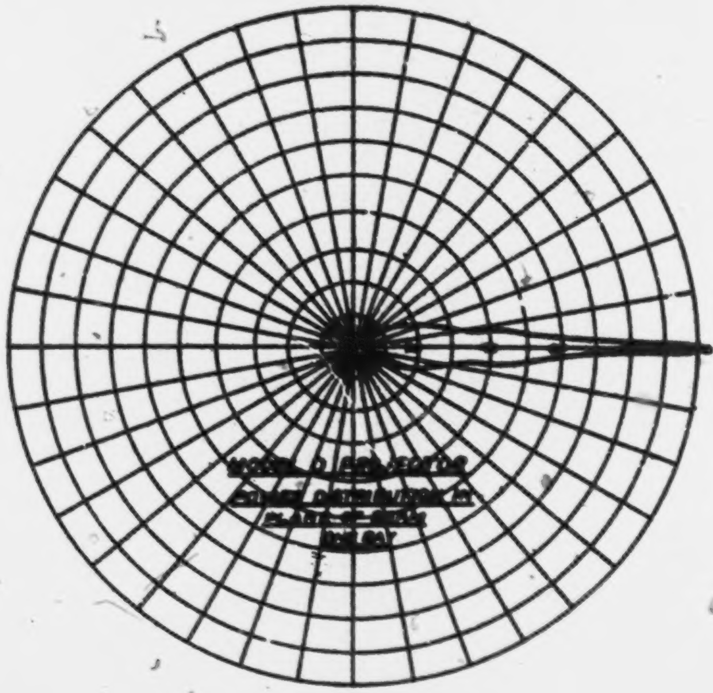


Fig. 59

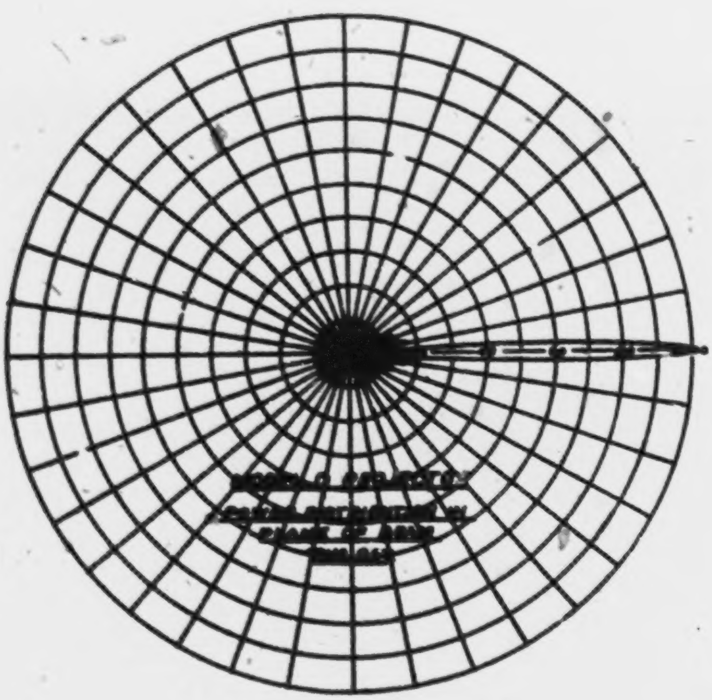


Fig. 60

607
794

The directivity is, according to the definition given:

$$D = \frac{\bar{P}_{max}}{\frac{1}{4\pi}\int_0^{2\pi}\int_0^{\pi}\bar{P}\sin\theta d\theta d\phi} \quad (99)$$

The expression for $\bar{P}$ is so extremely complex that the evaluation of the surface integral by other than graphical or mechanical processes would no doubt be impractical. The computations necessary to determine the curves for evaluating by means of a planimeter involve a large amount of labor even when carried out with slide-rule accuracy. The following table gives the directivity, and power ratio to a half-wave dipole as arrived at by such calculations:

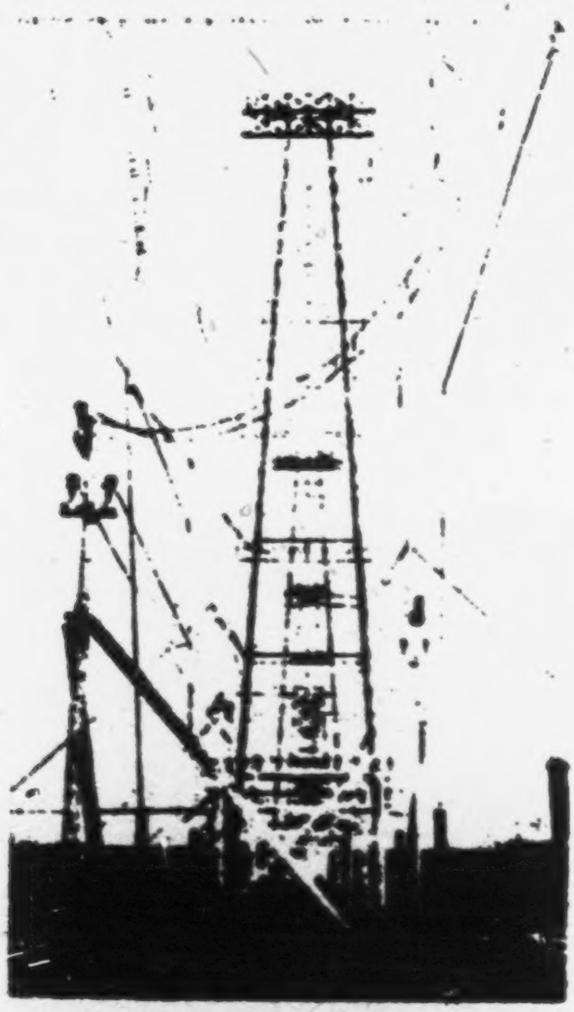
Number of Sections	*Directivity*	*Power Ratio to Dipole*	*Decibels Gain Over Dipole*
One	64	39	15.9
Two	128	78	18.9
Three	192	117	20.7
Four	256	156	21.9

Such theoretical calculations cannot completely determine the effectiveness of antenna systems because they do not take into account the phenomena of propagation between transmitter and receiver. It has been found by experiment that the actual results obtained are as would be expected from the calculations.

[redacted]

PLAINTIFF'S EXHIBIT No. 22

SHORT-WAVE TRANSATLANTIC RADIO-TELEPHONY



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Fairchild Aerial Surveys, Inc.

A general view of the transmitting station at Lawrenceville, New Jersey

The American Radio Stations

By W. WILSON
Assistant Director of Research

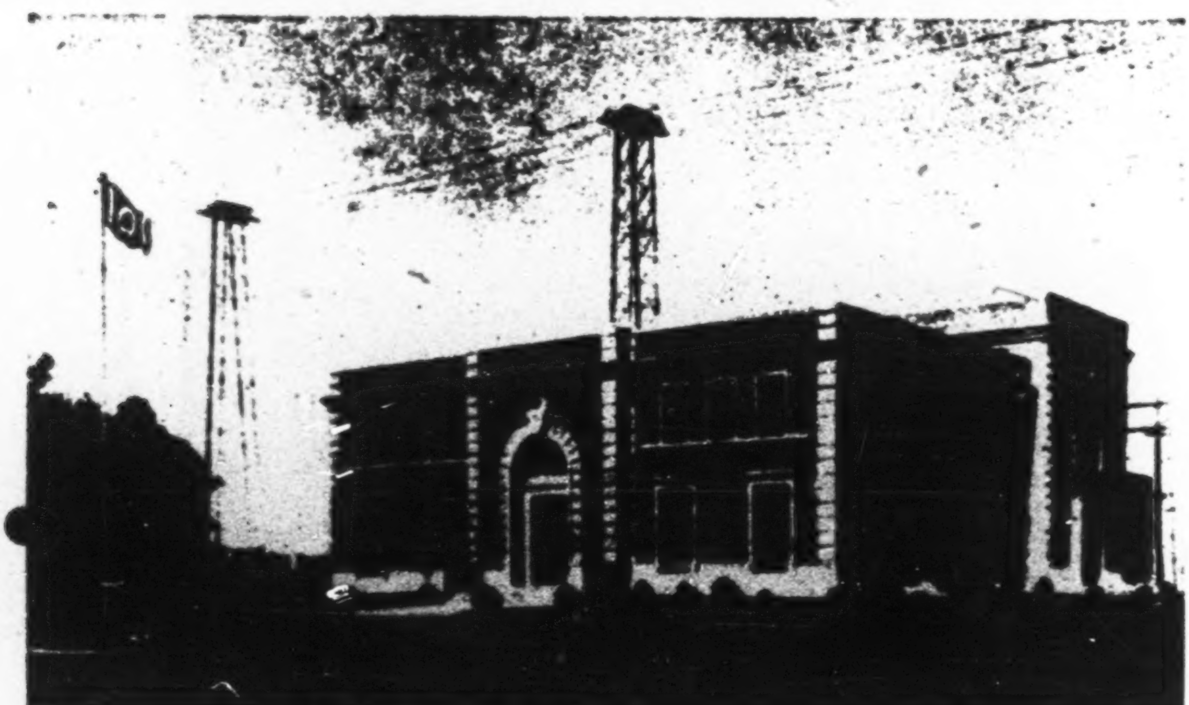
NEW short-wave stations for transoceanic communication have been opened at Lawrenceville, New Jersey, for transmitting and at Netcong, New Jersey, for receiving.

Four channels will be put into operation. One of these will replace the present experimental channel, through which messages have been transmitted from our Deal Beach station and received at Netcong for the last two years.

Two of the others will be added to the European service during the coming months, and the fourth will establish telephone communication with South America.

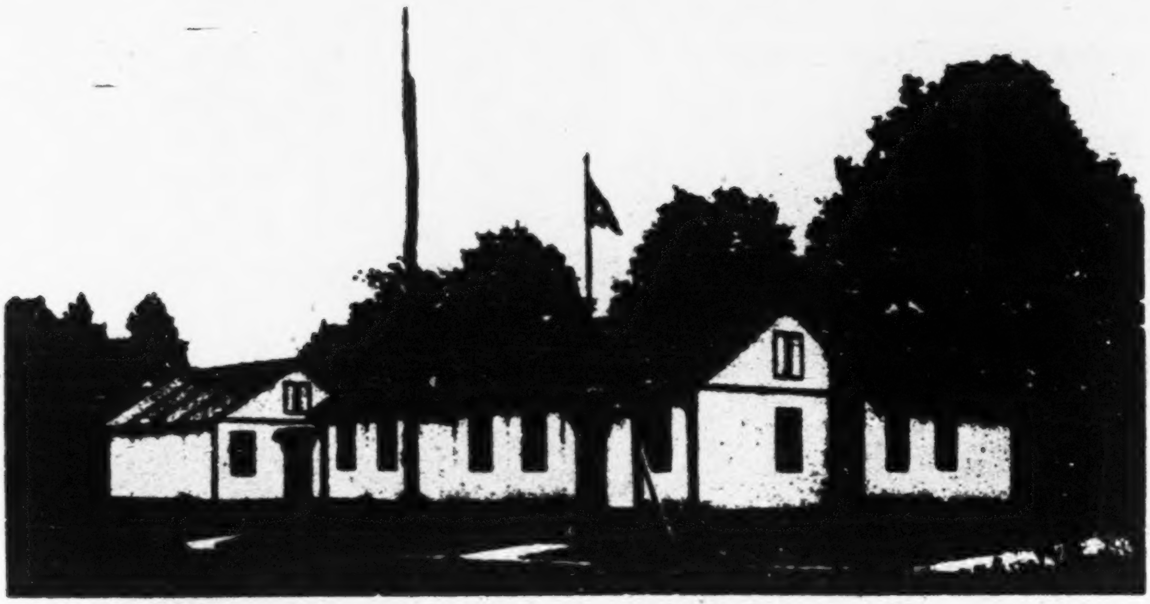
The Lawrenceville property is approximately 800 acres in extent and has two buildings The main building houses the general offices and line terminal equipment in addition to two of the radio transmitters. The second building is similar to the first except that provision is merely made for the radio equipment.

Each transmitter is designed for operation on those frequencies in the short-wave range which are found to be necessary for communication during the hours of operation. These frequencies are approximately 19,000, 14,000, and 9,000 kilocycles, corresponding to 16, 22, and 33 meters wavelength.



Antenna towers and main building at Lawrenceville

22/b



Buildings at Netcong

Carrier power at these frequencies is obtained by amplification of the suitable harmonics from crystal oscillators with fundamental frequencies in the neighborhood of 3,000 kilocycles. Considerable care is taken with regard to constancy of temperature and other operating conditions to ensure the stability of these oscillators.

By the usual method of plate modulation, the voice signals are applied to the carrier, and the modulated power is in turn amplified by two stages employing water-cooled tubes. The output from the sets is fed by transmission lines to appropriate antennas, located in some cases several hundred feet away.

Power for the transmitter is purchased from central-station lines. After transformation to appropriate voltages, that required for plate circuits is rectified and filtered. For the two final stages power is delivered at 10,000 volts from a rectifier employing six water-cooled tubes. Elaborate precautions are taken to insure safety in operation by an interlocking system which prevents the opening of any enclosure before the power has been shut off. In addition the doors of the apparatus are equipped with safety switches which throw the main circuit breaker when the doors are opened if there should be any failure of the interlocking system.

One of the advantages of a short-wave system is its adaptability to the use of antennas which concentrate the transmitted energy into a beam in the direction required. This greatly enhances the signal at the receiver.

In general, directive antennas are suitable for only one wavelength. Since each transmitter must be able to work on any of three wavelengths, nine antennas are required. These consist of curtains of vertical and horizontal wires strung between towers 180 feet high and 250 feet apart. Each antenna is 500 feet wide and the nine antennas are lined up end to end giving a total length of 4500 feet. The gain to be expected from the use of these antennas over a single vertical wire is from fifteen to twenty decibels.

The Netcong receiving station com-

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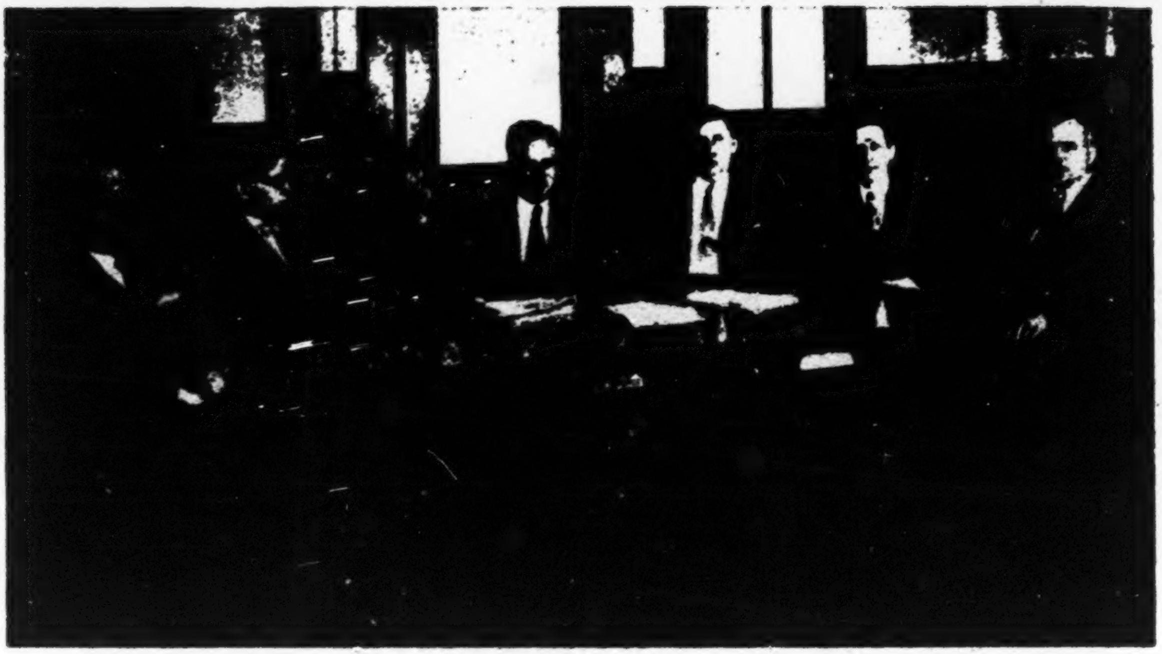


Engineers in charge of the development of the short-wave radio transmitters and receivers. Left to right: A. A. Oswald, M. J. Kelly, W. Wilson, R. A. Heising, J. C. Schellong, H. T. Friis

prises about 400 acres. As in the case of the transmitting station three wavelengths are needed for each of four receiving sets, necessitating the use of 12 antennas. Each receiving set is housed in a separate building and the general offices and power plant are in still another building.

The receiving sets have two stages of radio-frequency amplification, six stages of intermediate amplification and one stage of audio amplification. An automatic volume control minimizes fading effects. Actual volume at which the energy is put on the telephone line is adjusted by means of repeaters in the line terminal equipment.

The antennas used at the receiving end are also directive. Their directivity not only makes them more efficient from the standpoint of picking up signals from a preferred direction but it also by its discrimination against signals coming from other directions materially reduces interference both from static and from other stations. The antennas are six wavelengths long and are connected to their respective sets by transmission lines.

In selecting a site for the receiving station great care was taken to avoid the proximity of well-travelled automobile and airplane routes, because of the interference with signals created by unshielded ignition systems. With the adoption of radio communication for airplanes their ignition systems must perforce be shielded but no relief can be expected from interference from the present type of automobile engine. Limits have been prescribed beyond which automobiles are not permitted unless their ignition systems are adequately shielded. Horses are used for much of the transportation immediately around the station.

22/5

Transmitting Antennas

By E. J. STERBA
Radio Research

THE antenna system is the first object to attract the attention of a visitor to the plant at Lawrenceville, N. J., for the tower line west of Princeton is visible several miles from the station. Upon arriving at the station grounds, the antenna system appears to be a complicated network of wires on rugged towers extending more than a thousand feet past the observer. Appreciating that this extended construction is associated with directive transmission, he may feel that the structure is far too complicated for ready explanation. Yet the fundamentals of directive transmission and thus of the antenna are quite simple.

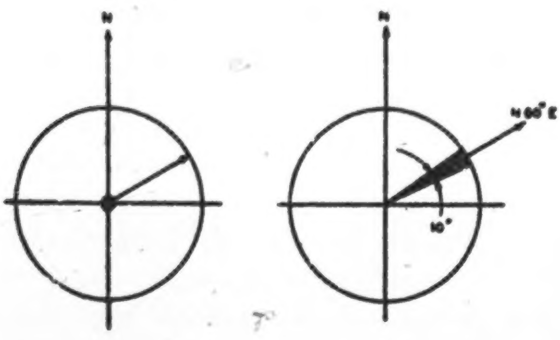


Fig. 1-*A* (*left*)—*Electric intensity about a broadcast transmitter. The area of the circle is proportional to the power radiated;* *Fig.* 1-*B* (*right*)—*Shaded area represents energy radiated if transmission is confined to a ten-degree sector*

A background of broadcast experience has familiarized nearly everyone with a transmitting antenna. The broadcast antenna is constructed so as to radiate in all directions with equal intensity, because broadcast reception is generally desired in all directions about the station. For this purpose a single vertical wire or several closely spaced vertical wires may be employed. If a vertical-wire antenna is erected upon an ideal transmitting site, the electric intensity in any direction about the antenna and for a constant distance from the antenna may be represented by the radii of a circle (Figure 1-A), signifying equally good reception in all directions about the antenna. The area of the circle is approximately proportional to the power radiated.

If, however, radio transmission is required only between two points, the radiation of energy in all directions other than that in which the receiving station lies is wasted effort. Suppose, for example, that the receiving station is located at N60°E with respect to the transmitter. If some modification is made in the antenna so that radiation occurs only between the radii five degrees to either side of the direction to the receiving station, and if the power of the radio transmitter is readjusted so that the signal-strength from the simple antenna and from the modified antenna are equal at the receiving station, the area of the shaded ten-degree sector in Figure 1-B is proportional to the power radiated—10/360 of that required

for the simple antenna. If this ideal case could be set up, the radio transmitter connected to the modified antenna would consume one thirty-sixth of the power formerly consumed. In telephone nomenclature, an equivalent signal strength would be secured from a source 15.6 decibels lower in power level. It is thus of some economic importance to determine how an antenna may best be modified so that radiation is confined to a narrow sector within which lies the chosen direction.

Heinrich Hertz, who in 1887 and 1888 discovered means for producing and detecting radio waves, constructed the first directive antenna. Employing wavelengths of less than one meter, Hertz experimentally concentrated radio waves in a chosen direction by means of a short antenna lying in the focus of a metallic parabolic surface (Figure 2). In principle the scheme was very much like that of an automobile headlight. Hertz also observed that radio waves of the same length from different sources produced interference patterns—recurring positions of intense and feeble signal-strength—near the sources.

Parabolic reflectors similar to Hertz's experimental antenna have been employed for a number of years in short-wave radio transmission. It is essential that the dimensions of the parabolic reflecting surface be several wavelengths, and hence it is impracticable that the surface be a conducting sheet except for use at very short wavelengths. This difficulty was overcome by using a number of wires, spaced so as to outline the surface, and set at critical lengths so as to be resonant at the operating wavelengths.

Interference, well known with light waves and observed by Hertz with radio waves, is an alternative method for producing directive transmission.* If two or more narrow parallel slit-sources of monochromatic light are directed upon the same surface an interference pattern is produced, visible as a family of light and dark strips. It is brought about by the difference in phase of the radiation from the two

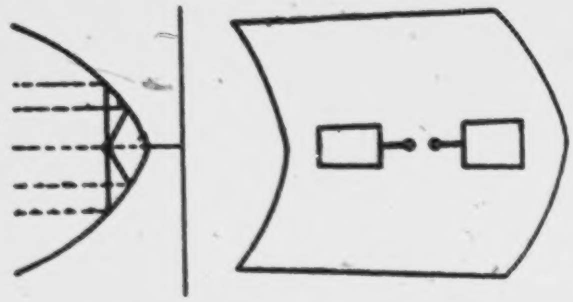


Fig. 2—Parabolic reflector employed by Hertz. The antenna is at the focus of the metallic parabolic surface

sources due to the difference in length of path between the two sources and the screen.

Directive radio transmission by means of wave interference may readily be obtained by transmitting simultaneously from the same transmitter with two or more suitably spaced antennas. If two antennas, one wavelength apart and each carrying unit current, are driven in phase, the electric intensities from both antennas, several wavelengths away in the direction normal to the two, are in phase because the paths from the antennas to the receiving point are equal. The field in this direction is the sum of the fields from the individual antennas. If, however, a direction thirty degrees from the normal is considered, the path from one antenna is one-half wavelength longer than from the other, and the time it consumes

The "reflectors" discussed in the preceding paragraph depend ultimately, of course, on interference also.

in traveling this additional distance puts the radiation from one antenna one-half pe·iod behind the other. The intensities in this direction are exactly out of phase and thus the net intensity is zero. By simple trigonometry

Fig. 3—Directive intensity characteristics for: (A) two antennas spaced one wavelength apart and driven in phase; (B) two antennas spaced one-quarter wavelength apart and driven ninety degrees out of phase (B leads B')

the polar diagram of Figure 3-A may be obtained, representing the intensity in all horizontal directions about the antenna. The radii of the circle enclosing the four-leaf figure represents the intensities which would be realized if the two antennas were very close together.

Forming an example of another simple directive system are two antennas spaced one-quarter wavelength apart and driven ninety degrees out of phase with each other. Since a quarter period is consumed in traveling the distance between antennas, the radiations from the antenna which bears the current lagging ninety degrees will lag an additional ninety degrees upon arriving at the adjacent antenna, and the fields from the two antennas will cancel in this direction. In the opposite direction the fields both lag the same amount and are additive. The polar diagram for this case is given in Figure 3-B, in which again the circle enclosing the figure represents the radiations which would proceed from the two antennas if these were coincident and in phase. It has been found by experiment that two antennas will form this second system if one is driven by the transmitters and the other is parasitically excited. The parasitic antenna is usually called the "reflector antenna."

The above two schemes may be combined in several possible ways to give unidirectional systems. In general the polar diagram of the combined system may be obtained by superimposing the two diagrams and multiplying by each other the lengths of the coincident radii to obtain the lengths of the new radii.

Simple directive systems, such as

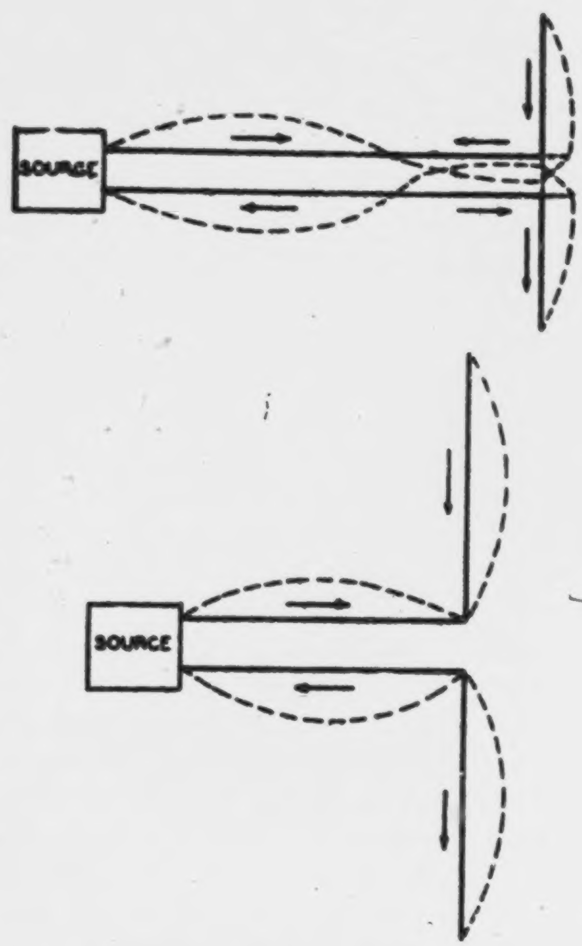


Fig. 4-A (above)—Line bent into a Hertz antenna; Fig. 4-B (below)—Line bent into two Hertz antennas

those described, were proposed by S. G. Brown in 1899 and J. S. Stone in 1901, and many others have since devised increasingly complex and more efficient schemes. Later G. A. Campbell, of the American Telephone and Telegraph Company, proposed a directive scheme comprising several rows, each bearing several antennas in suitable phase relations. He established in a general manner the relations between the spacings and phasings and devised methods whereby the performance of the system, however complex, could be predicted.

In the polar diagrams, the area of the figure, as compared to the area of the enclosing circle, is approximately proportional to the relative power consumption of the directive and the non-directive systems and thus an approximation of the gain of the directive system may be obtained by expressing the ratio of the areas in transmission units. The reason for this gain may be suggested by another simple example. If two antennas, several wavelengths apart, each have a resistance R and carry a current I, the total power consumed is $R\ I^2 + R\ I^2 = 2\ R\ I^2$. The intensity at a point where the radiations are in phase is proportional to 2 I. This same intensity could be obtained by exciting one antenna alone with 2 I units of current but the power consumption would then be $4\ R\ I^2$, or twice as much as before. In general the improvement factor of a directive antenna is nearly proportional to the number of antennas, when they are separated by more than about one-half wavelength. This is only approximately true because two antennas, when close together, react upon each other.

There are many methods for the mechanical construction of directive antennas; that now being employed at Lawrenceville depends upon the manner in which waves stand upon transmission lines. It is generally known that the current in an open-circuited line recurs along it in standing maxima

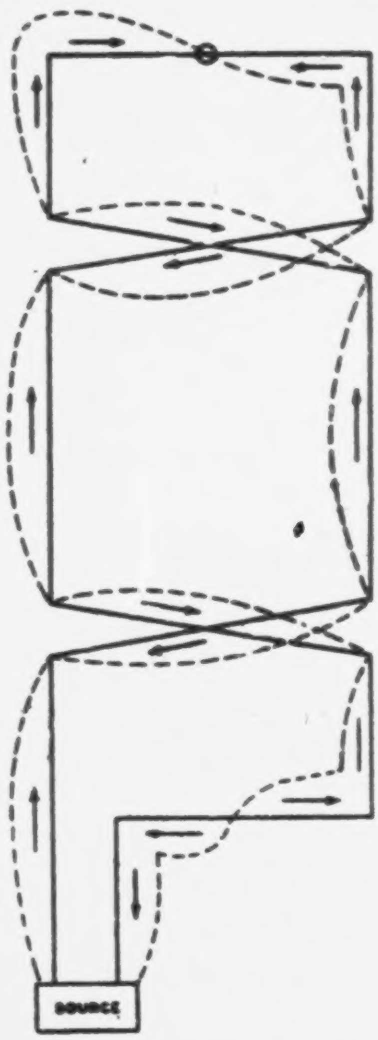
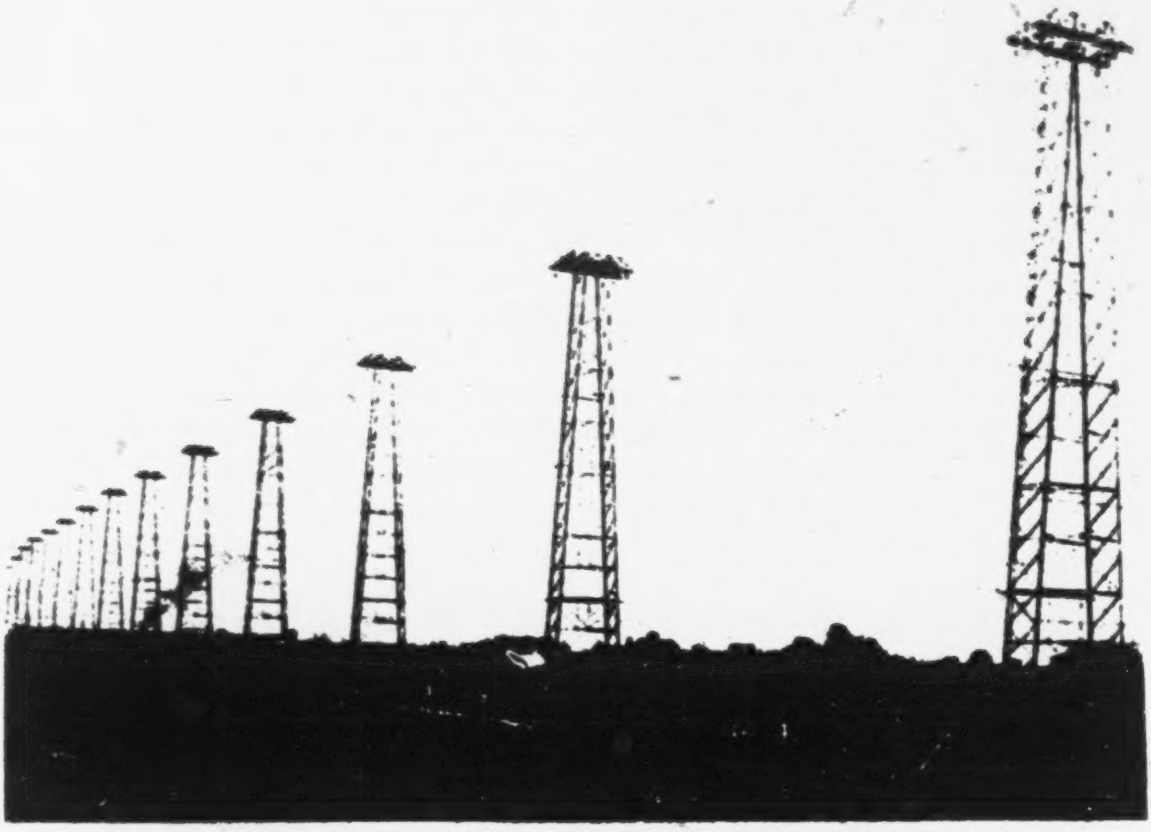


Fig. 5—A panel for the Lawrenceville antenna system. The vertical members are radiators; the crossed members are transmission-line phase shifters. The line may be open or closed at the center of the top cross-piece, since there is a standing-wave node, and thus no current flow, at that point

and minima, that the phase difference between successive current maxima is 180 degrees and that the phase difference between corresponding points



A part of the line of towers supporting the antennas

on the two wires is 180 degrees. The radiation from an open-circuited line is small, but if the ends of the line are bent outward, the radiation from these ends will be greatly augmented and the balance of the line will act largely as a means for transmitting power to the radiating end. If the bent portions are each one-quarter wavelength long, a one-half wave Hertz antenna is formed (Figure 4-A). An even more efficient antenna may be formed by bending over a one-half-wave portion of the line; in this case the bent-over portion is equivalent to two Hertz antennas driven in phase (Figure 4-B).

Thence it is only a small step to the panel arrangement of the Lawrenceville antenna system (Figure 5). Here the vertical wires are the radiating members, all excited in phase, and the horizontal pairs are transmission lines for distributing the current to the radiating elements in the desired phase-relations. The panel is equivalent to four Hertz antennas, two of which are stacked one above the other and of which the two groups thus formed are spaced one-half wavelength apart. Complete reinforcement of signal intensities takes place only in the horizontal direction normal to the panel. In all other directions destructive interference occurs; complete cancellation occurs in the plane of the panel.

By computation and by experiment it has been shown that a power improvement of four decibels is acquired from the horizontal spacing of one-half wavelength, and of two decibels from the vertical stack of two. The net power saving is approximately six decibels: the panel consumes but one-fourth the power which would be re-

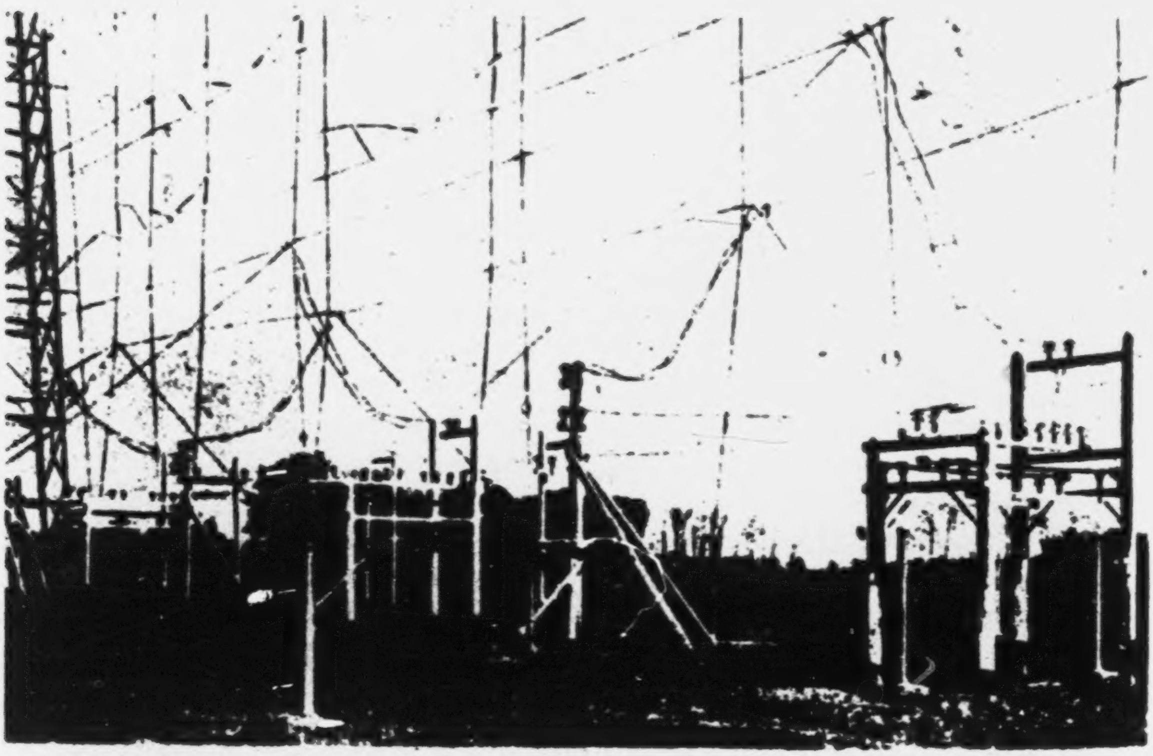
quired by one element to produce the same intensity in the chosen direction.

A second similar panel, excited parasitically, is placed one-quarter wavelength behind the first to act as a reflector and thereby create an unidirectional system. It has been found that the reflector reduces the power required to maintain a given intensity in the desired direction by approximately three decibels, and thus brings the gain of the two-panel system up to nine decibels. The two-panel system, therefore, requires but one-eighth the power which would be necessary in a simple antenna producing the same intensity in the desired direction.

Larger power savings may be effected by employing many antennas properly connected together. Practically, however, considerations of mechanical construction, investment and maintenance limit the size of the system. The complex nature of short-wave transmission also leads to a lowering of the optimum size of the antenna. For wavelengths of the order of sixteen meters, improvements of twenty decibels (a power ratio of one hundred) are practicable.

The connection of a number of antenna panels to a common feeder line must accomplish proper phase and impedance relationships. The former may readily be obtained through adjusting the lengths of interpanel lines, by tape-line measurements. The conventional methods for building up the load impedance to the surge impedance of the feeder line, however, are far from satisfactory for high-power work at short wavelengths. In this case one of the less familiar properties of a transmission line is used for transforming impedances.

If a line of surge impedance Z_o, exactly one-quarter wavelength long, is terminated with a load Z_a, the



Lower edge of antenna curtain, and frames supporting the quarter-wave lines for effecting sleet-melting connections and proper terminating impedances

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sending-end impedance of the line is Z_o^2/Z_R and, if Z_R is a pure resistance, the sending-end impedance is a pure resistance. Such a quarter-wave line is employed in the Lawrenceville antenna system. Since a line bearing standing waves is being terminated at one upon which standing waves are not desired the receiving-end of the quarter-wave line is connected at either a current maximum or minimum, to ensure a resistance load.

A transmitting antenna is adversely affected both mechanically and electrically by sleet. The sleet load may strain the system to the breaking point and thus put the antenna out of service for a long period, and the mass of ice, having a dielectric constant of eighty, may detune the antenna and destroy the effectiveness of the system. Sleet is, therefore, removed in the Lawrenceville system, by heating

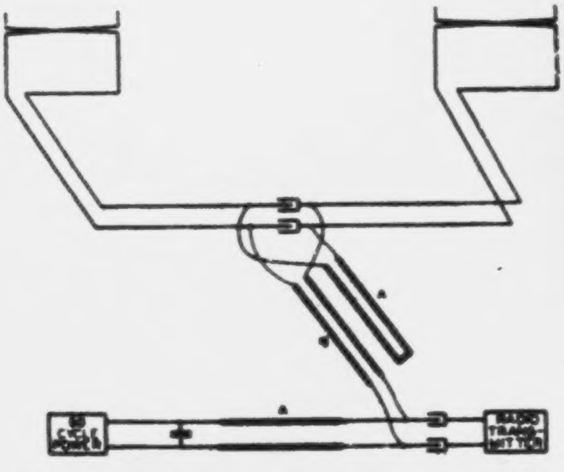
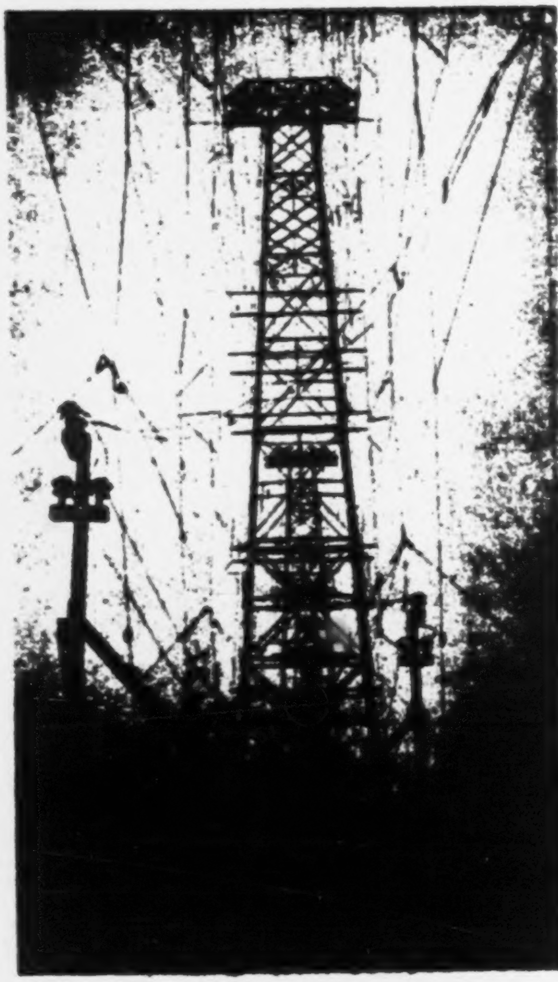


Fig. 6—Antenna connections for melting sleet from the Lawrenceville antenna

the wires with low-frequency currents of about 150 amperes at a potential of nearly a thousand volts in each antenna. All elements in the antenna are arranged to be in series for the low-frequency currents and the vertical elements in phase for the radio-frequency currents (Figure 6).

Another relatively unfamiliar property of transmission lines is utilized to effect this arrangement. If a line one-quarter wavelength long is short-circuited at the receiving end, the sending-end impedance is very large. Such



Looking down a tower line at Lawrenceville. Photo by G. M. Eberhardt of the Research Department

a line may be connected across a circuit of relative low impedance without disturbing its radio-frequency functions. From Figure 6 it may be seen that the anti-resonant circuit of quarter-wavelength bars, in combination with several condensers which readily pass radio frequencies but which block low frequencies, and in combination with two antenna panels, forms a series

circuit for the low-frequency currents and the power source. The two panels, however, are in parallel with each other and with the feeder line at radio frequencies. Both the low and the high-frequency powers may be applied simultaneously to the antenna.

For three of the four communication channels at the Lawrenceville radio plant, the antenna system is supported by a row of nineteen towers at right angles to the direction of England; for the fourth, a row of seven towers is placed at right angles to the direction of Buenos Aires. Guys run along the top of these towers to anchors on the ground at the ends of the rows. The towers, 250 feet apart and 180 feet high, are designed to withstand the load of the largest antenna that can be supported in a bay, when covered with a coating of ice one-half inch in radius and subjected to a gale of ninety miles per hour. Each antenna occupies two tower-bays. The antenna-curtains themselves are supported by messenger cables and may be lowered or hoisted by individual winches; the curtains are constructed from No. 6 B&S wire and are held in position by insulated sections of steel harness. The several panels in each curtain are interconnected by transmission lines which lead to frames where proper connections are made and impedances built up to terminate the power leads from the radio transmitters.

The practicability of directive systems is dependent upon the shortness of the transmitted wavelengths. A twenty decibel antenna, operating on five hundred meters, would be approximately ten wavelengths or fifteen thousand feet long and two wavelengths or three thousand feet high. The investment in such a plant would probably never return dividends. Fortunately the wavelengths used in the transoceanic short-wave system are such that directive effects can economically be obtained.

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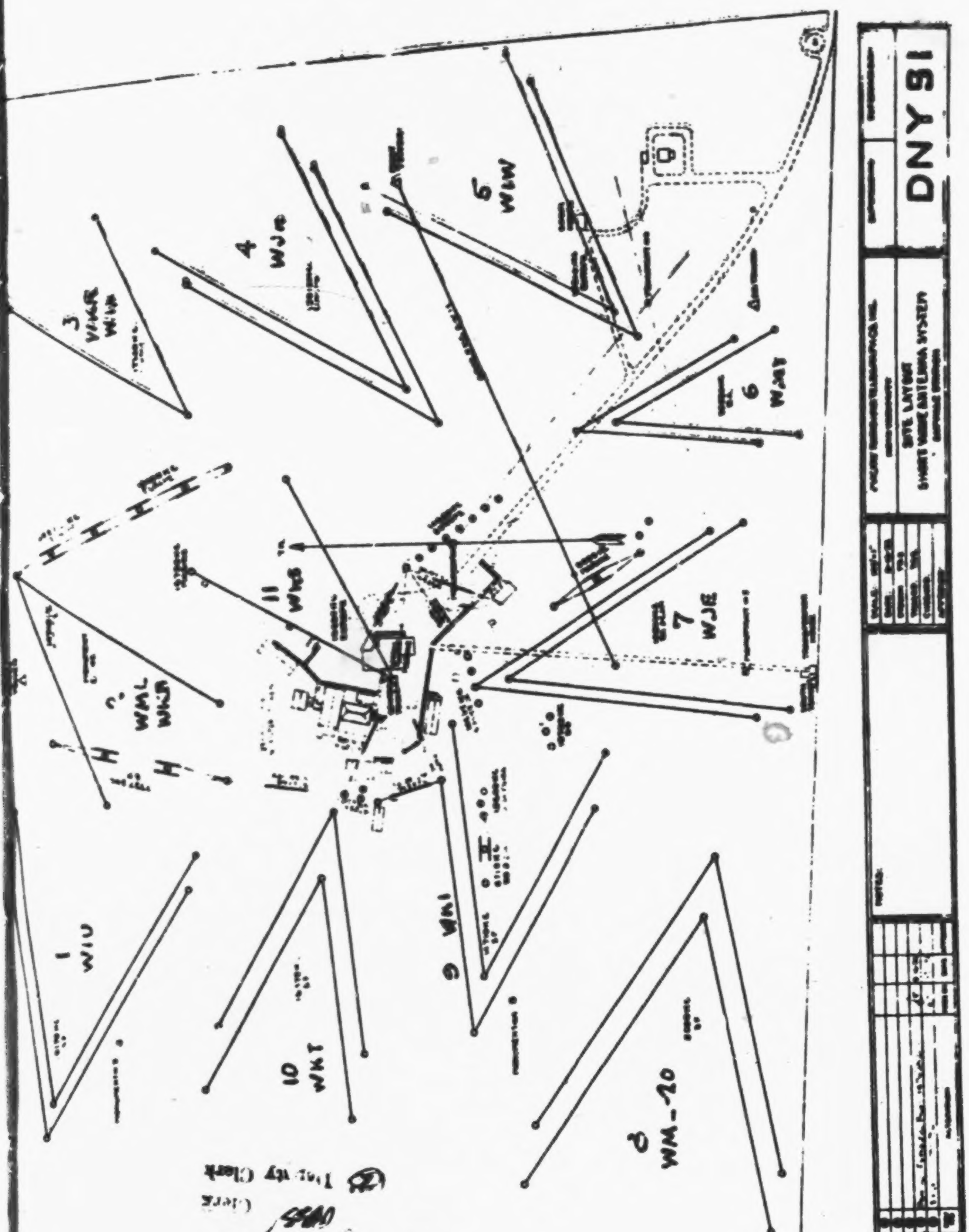
PLAINTIFF'S EXHIBIT No. 23 A



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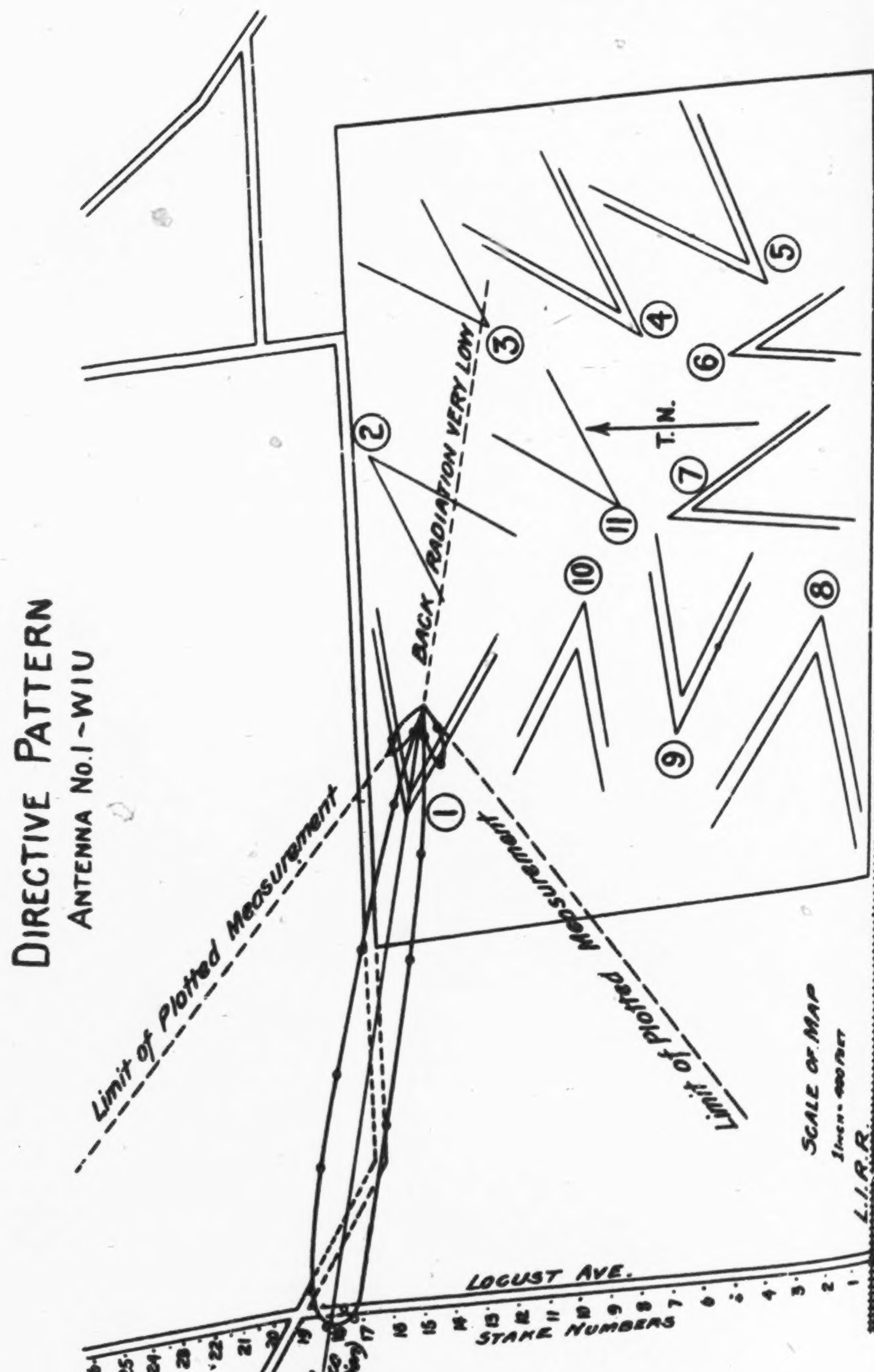

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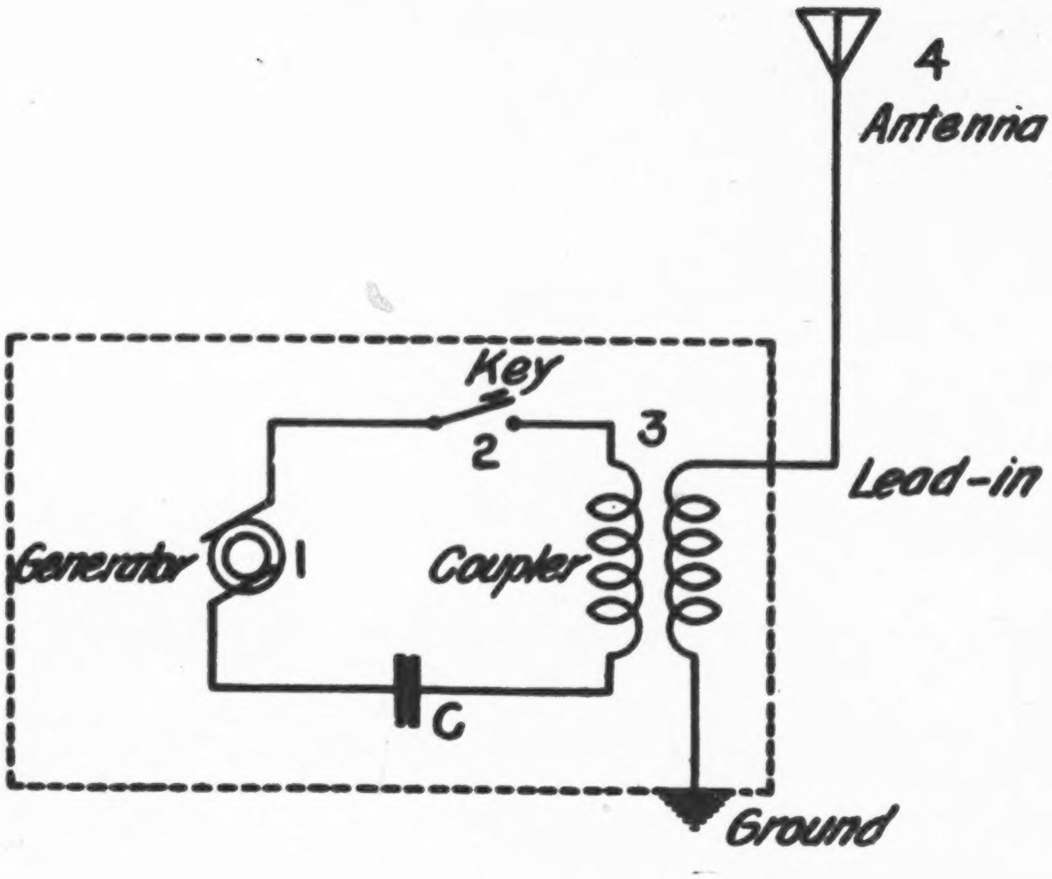


ELEMENTARY DIAGRAM OF RADIO TRANSMITTER

PLAINTIFF'S EXHIBIT No. 28

CHART OF WAVELENGTHS AND CORRESPONDING RADIO FREQUENCIES

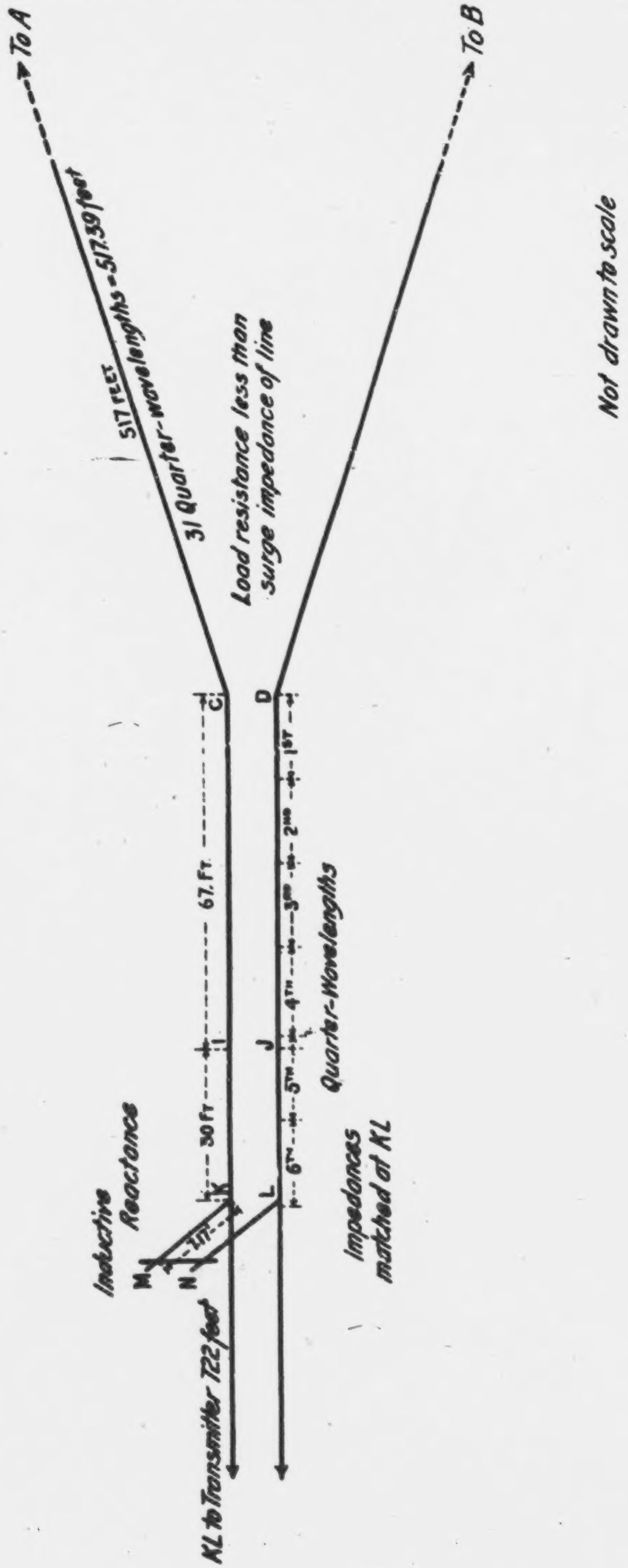
Wavelength	Frequency	
20,000 meters	15,000 cycles	or 15 kilocycles
15,000	20,000	20
10,000	30,000	30
5,000	60,000	60
3,000	100,000	100
1,500	200,000	200
1,000	300,000	300
600	500,000	500
300	1,000,000	1,000
200	1,500,000	1,500
150	2,000,000	2,000
100	3,000,000	3,000
50.08	5,990,000	5,990
29.5	10,170,000	10,170
20.35	14,740,000	14,740
14.3	20,980,000	20,980
10.	30,000,000	30,000

PLAINTIFF'S EXHIBIT No. 30

IMPEDANCE MATCHING OF ANTENNA SYSTEM No. 2 (ORIGINAL)-WML

Wavelength 20.35 Meters - 66.77 Feet

Quarter-Wavelength - 5.09 Meters - 16.69 Feet



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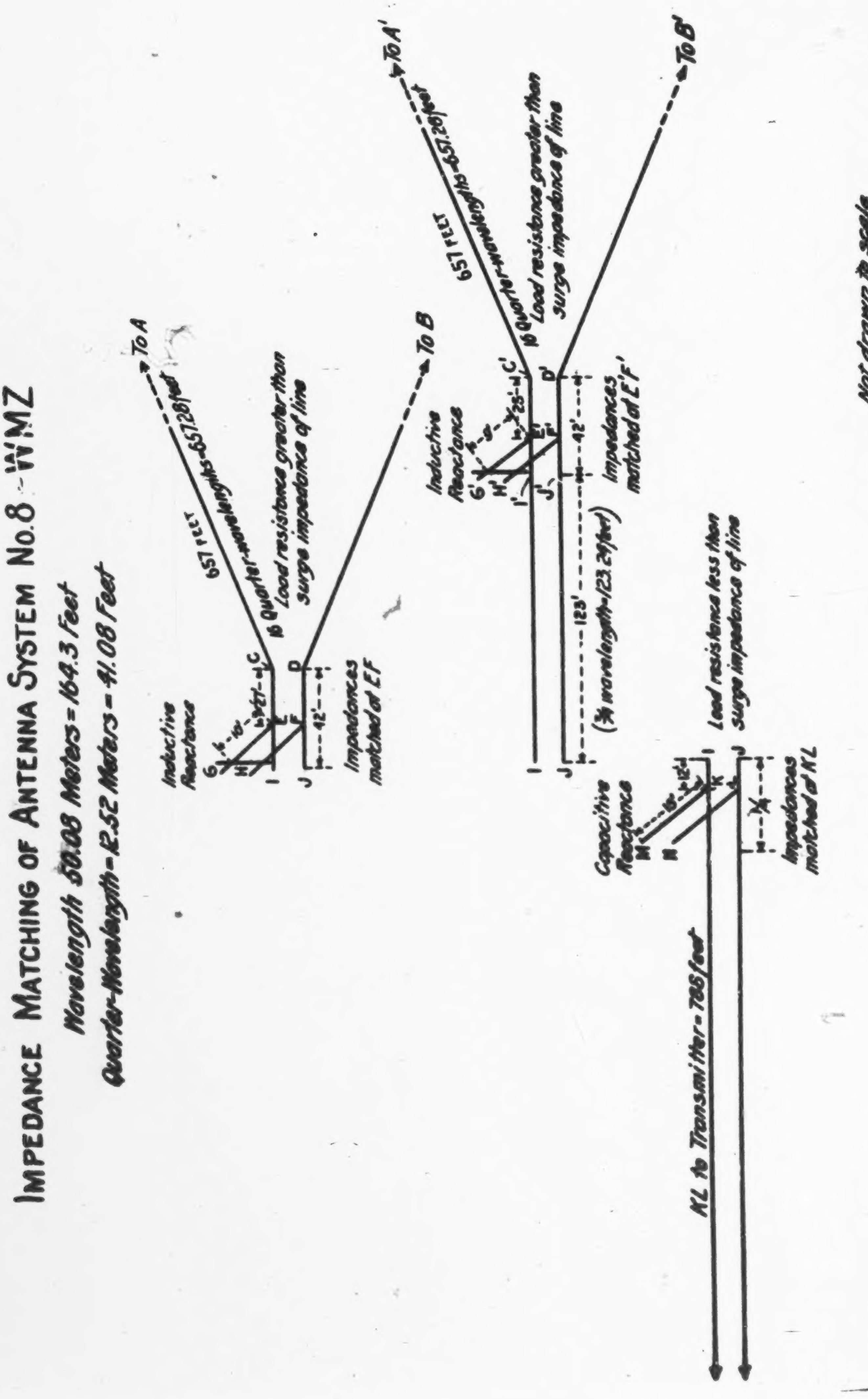
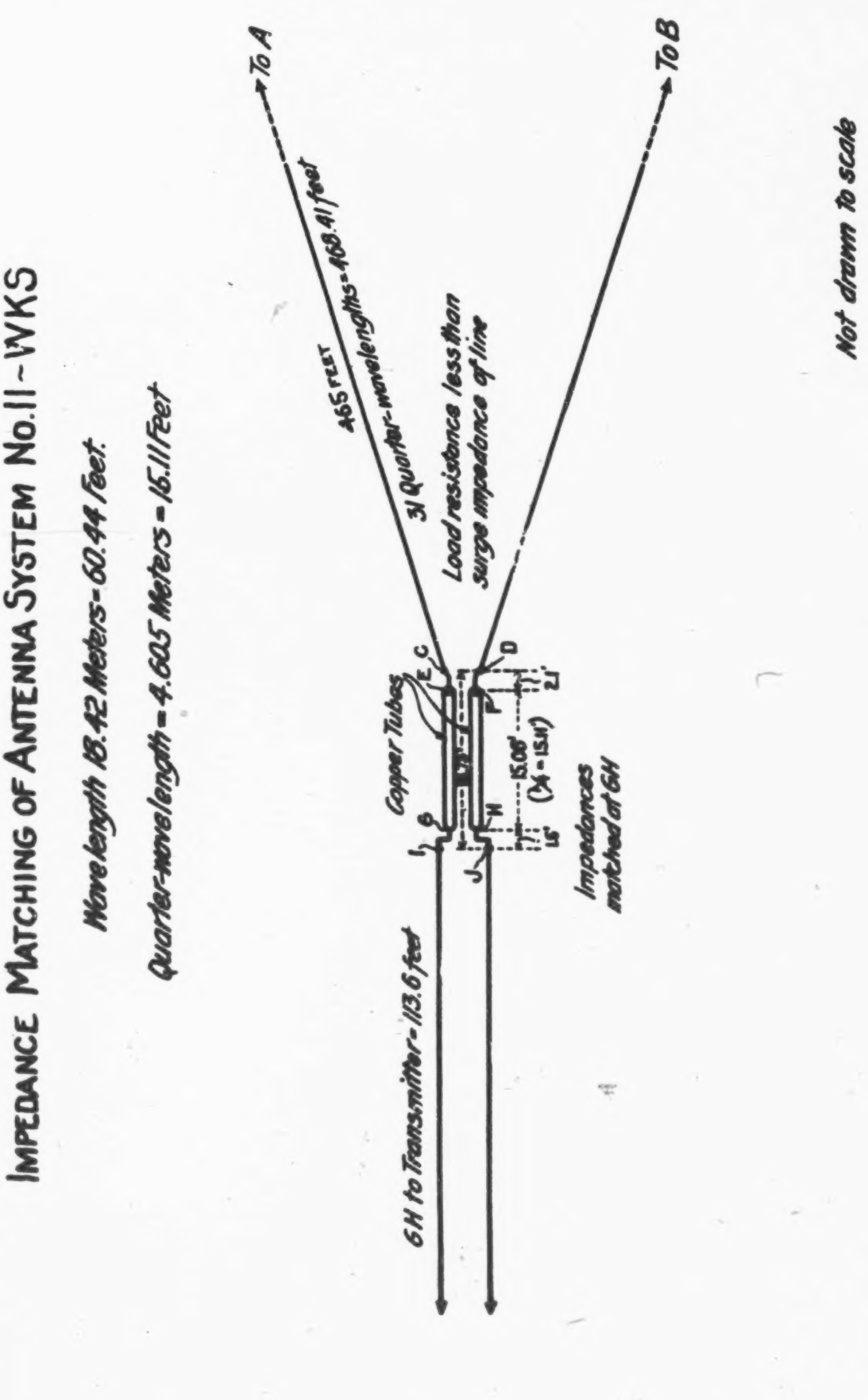


PLAINTIFF'S EXHIBIT No. 32 817-818



PLAINTIFF'S EXHIBIT No. 36

Free Space

4 λ wire

Perfect Ground

Practical Ground

Fig. 1

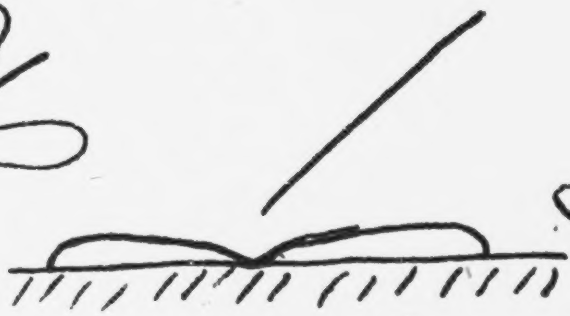


Fig. 4

Fig. 5

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Eastern District of New York
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Date Jan-15/36
[illegible] Clerk
[illegible] Deputy Clerk

Fig 4

"V" with 4 λ wires
(correct angle)

Fig. 2

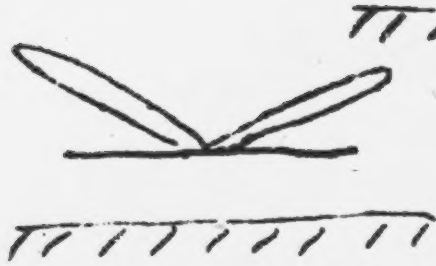

Fig. 3

PLAINTIFF'S EXHIBIT No. 37

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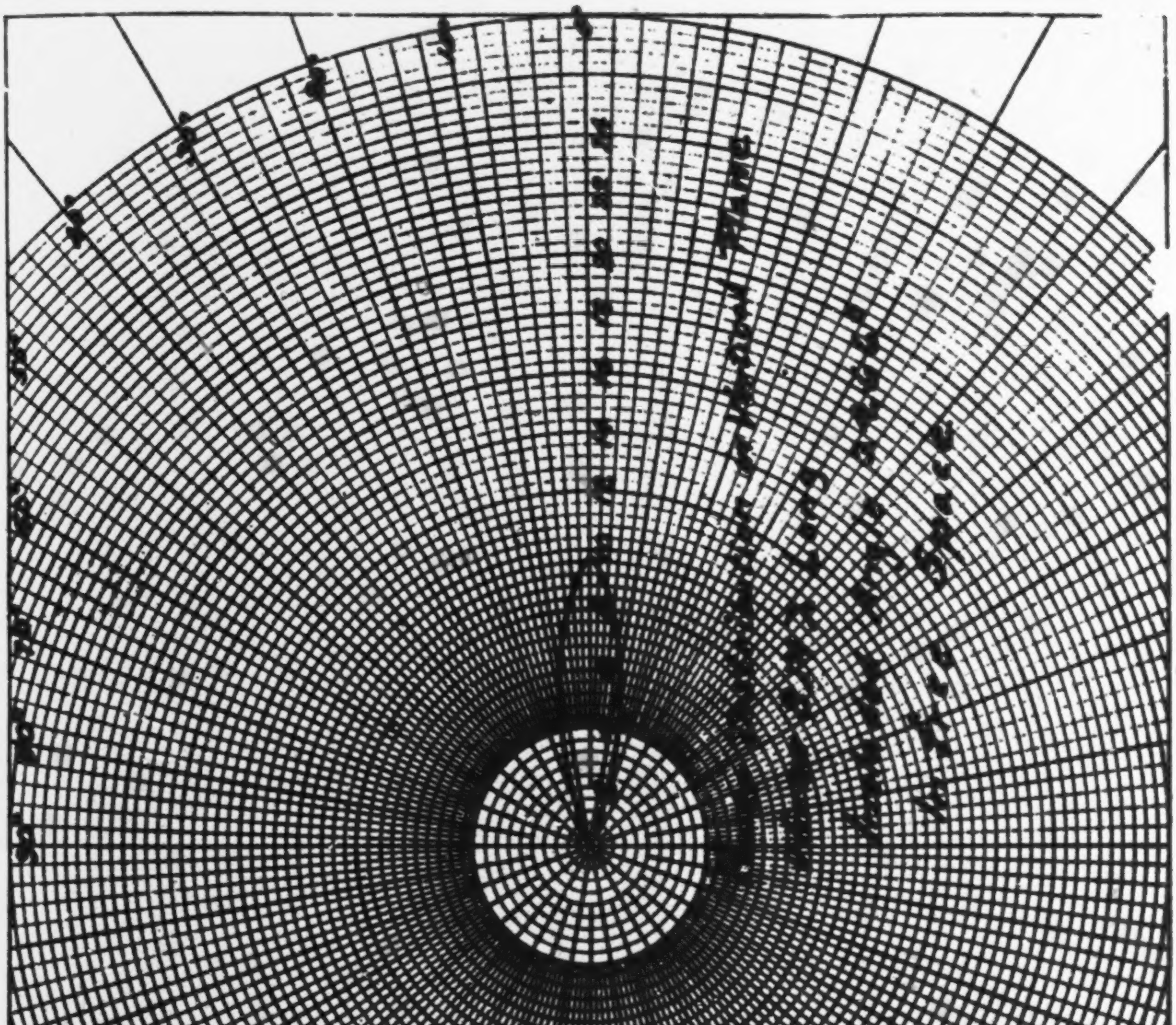
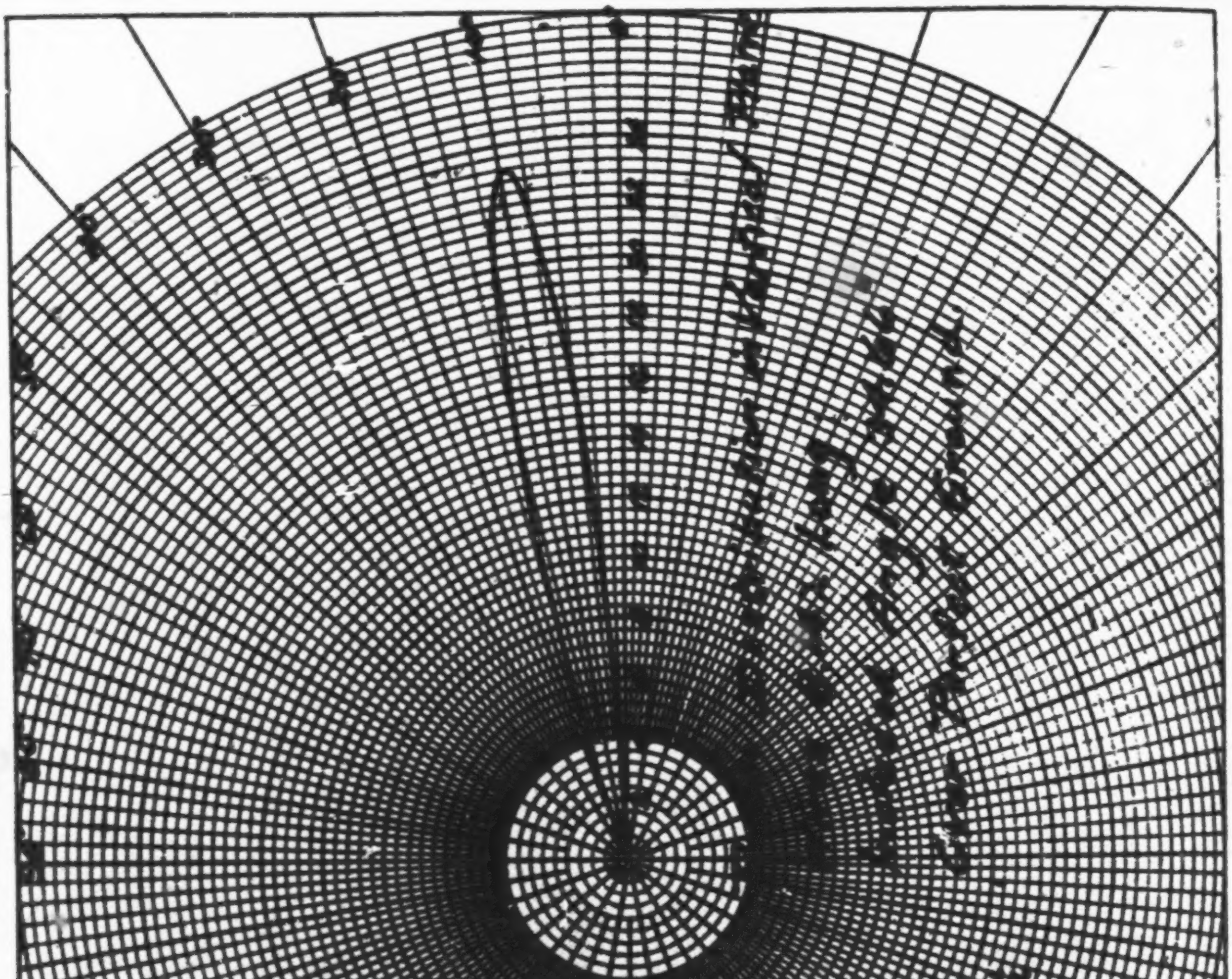


PLAINTIFF'S EXHIBIT No. 38



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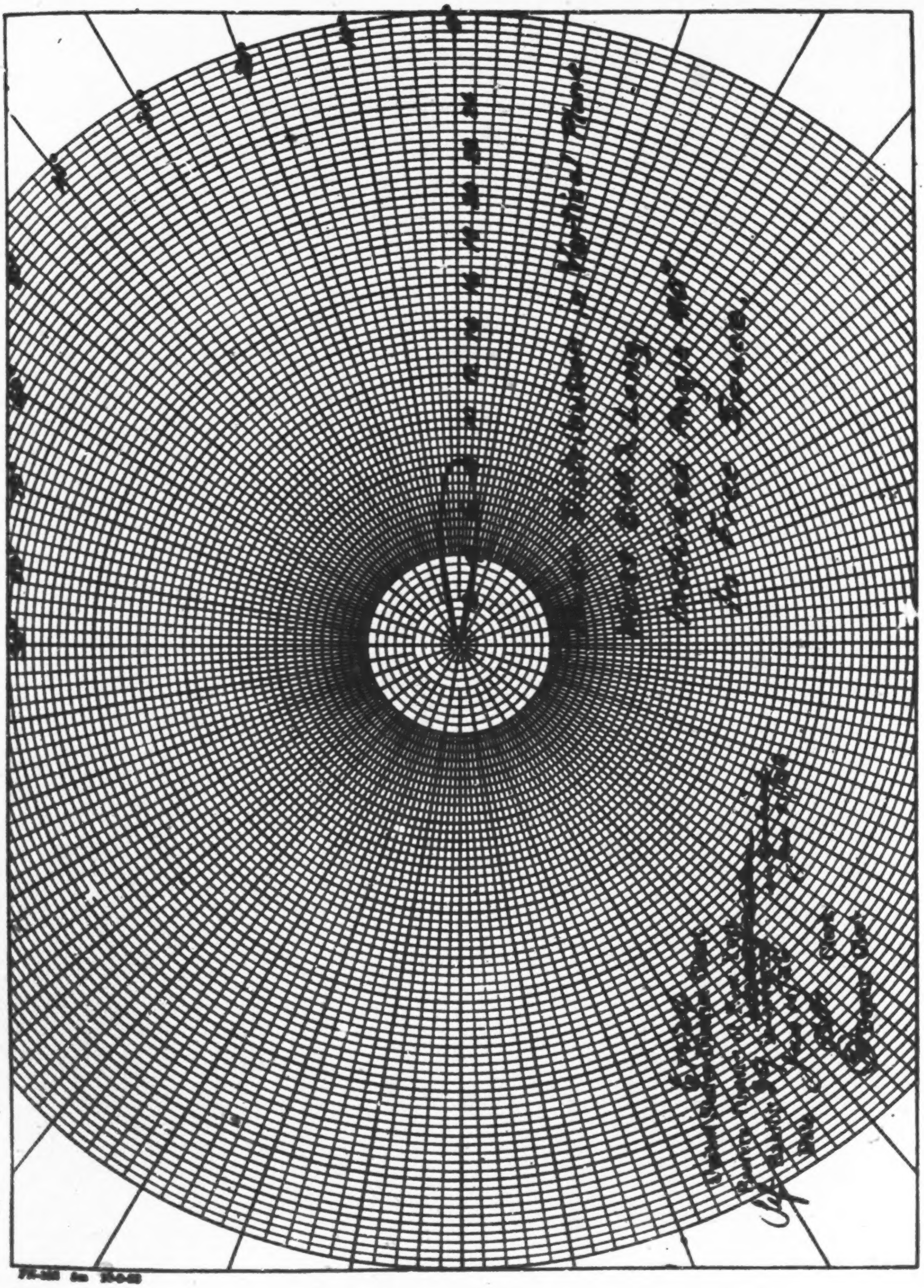
IF SHEET IS READ THIS WAY (HORIZONTALLY), THIS MUST BE TOP.
IF SHEET IS READ THE OTHER WAY (VERTICALLY), THIS MUST BE LEFT-HAND SIDE.



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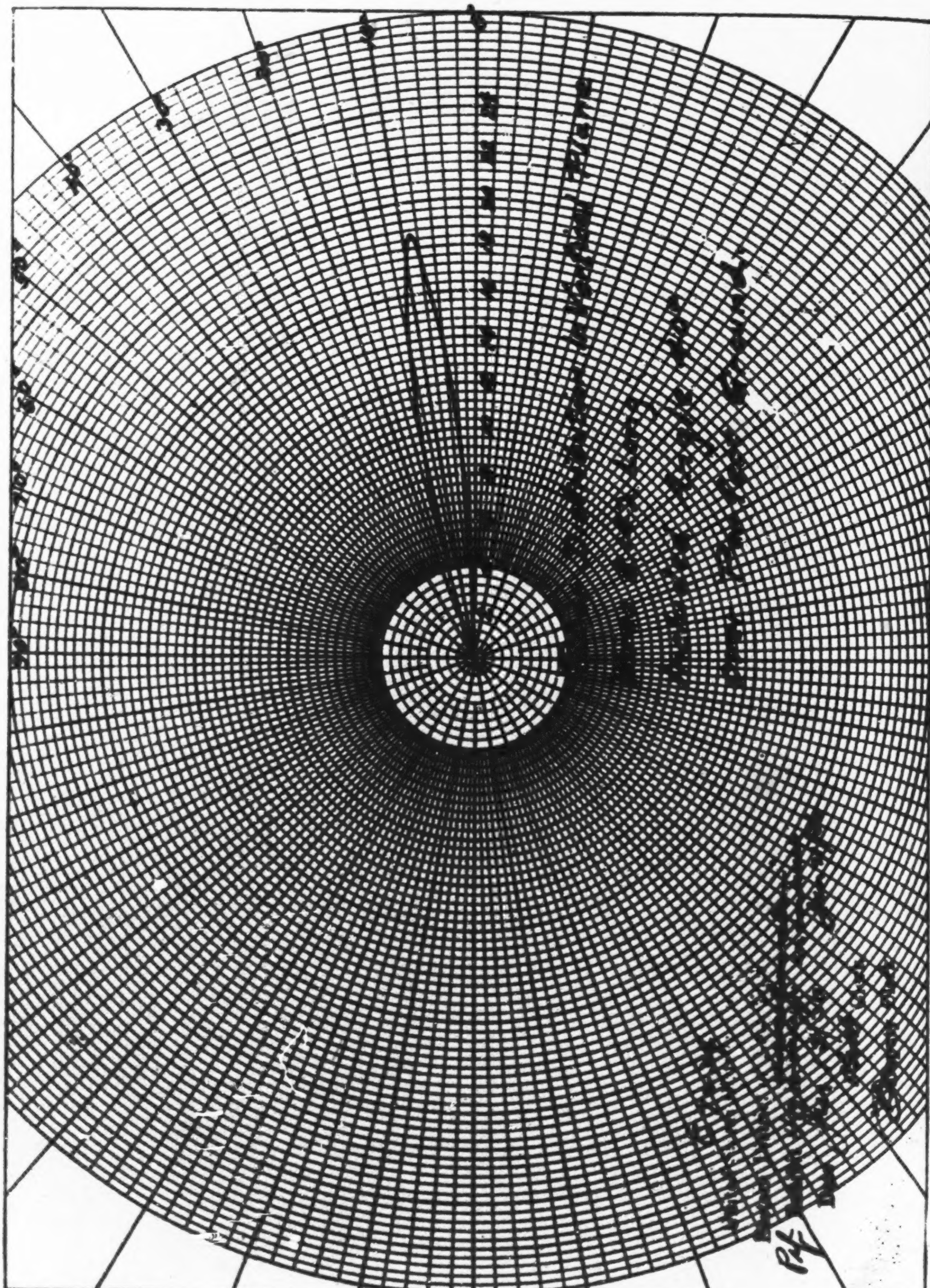

PLAINTIFF'S EXHIBIT No. 41

PATENT SPECIFICATION

392,201

Convention Date (United States): Feb. 3, 1931.

Application Date (in United Kingdom): Nov. 12, 1931. No. 31,365/31.

(Patent of Addition to No. 353,517: dated Oct. 11, 1929.)

Complete Accepted: May 12, 1933.

COMPLETE SPECIFICATION.

Improvements in Directional Antennæ.

We, STANDARD TELEPHONES AND CABLES, LIMITED, a British Company, Connaught House, Aldwych, London, W.C.2, England (Assignees of EDMOND BRUCE, of 27, Buena Place, Red Bank, Monmouth County, New Jersey, United States of America, a citizen of the United States of America), do hereby declare the nature of this invention and in what manner the same is to be performed, to be particularly described and ascertained in and by the following statement:—

This invention relates to aerial systems and more particularly to directive antennæ of the type according to our British Patent No. 353,517.

An object of the invention is to render directive antennæ of this type capable of effective operation over a considerable range of wave lengths.

Another object is to secure a relatively high angle of reception or emanation.

An additional object of the invention is to enable such an antenna to have a sharp selectivity.

A further object is to economise in the cost of supporting structures as compared with that of previous antennæ having directional characteristics.

A still further object of the invention is to increase its selectivity against undesired horizontally projected energy.

According to the present invention, we provide a modification of the antenna claimed in our British Patent No. 353,517, characterised in this, that a substantially horizontal antenna comprises a V-shaped conductor, said conductor comprising two members each having a length substantially equal to one-half wave length of the desired wave plus the projection of the member on the vertical plane of wave propagation.

Hence in accordance with the invention an antenna is constructed by mounting a Vee-shaped conductor so that its plane lies substantially parallel with the earth and with a spacing above it at least as great as one-half the wave length of the wave which is to be absorbed or radiated. The imaginary line joining the open ends of the Vee-shaped structure, in general, extend in the direction of incidence or emanation of the wave as the case may be. A similar Vee-shaped structure with its open ends closely adjacent those of the active antenna and lying in the same plane may be suitably connected thereto as a counterpoise.

Additional features and objects of the invention will be apparent from a perusal of the following specification taken in connection with the accompanying drawing in which Fig. 1 is a plan view and Fig. 2 a view in elevation of an antenna constructed in accordance with this invention. In both figures like reference numerals designate elements of similar function.

Reference numerals 1 and 2 designate the conducting members of the horizontal antenna proper each of which has a length equal substantially to one-half wave length plus the projection of the conductor on the vertical plane of wave propagation. The distant cooperating station is assumed to be included in the vertical plane containing arrows A and B, which represent the direction of desired reception or emanation, respectively. Reference numerals 3 and 4 designate conducting members of a counterpoise system, the length of each of which also equals a half-wave length of the desired wave plus the projection of the conductor on the vertical plane of wave propagation. The Vee antenna and counterpoise each resemble in structure, although having certain distinctive functional attributes, the inverted Vee antenna described in our British Patent No. 353,517. The chief point of difference and which determines its novel functional characteristics, is that the antenna described in our British Patent No. 353,517 is positioned in the vertical plane of wave propagation whereas both the antenna and counterpoise of this invention is positioned in a horizontal plane. The length of the antenna and counterpoise members are shown equal in the figure but they may differ without affecting the result obtained provided that the relation mentioned above between the

lengths of the member and its projection is maintained. By making the length of the antenna-counterpoise members equal to several, as for example, five or more wavelengths effective operation is secured over a band of frequencies inasmuch as the ratio of the projection of the member to its length for all such long antennas may be considered substantially equal to each other.

The antenna-counterpoise system is supported by means of wooden poles 5 and insulated therefrom by means of insulators 6. The translation device 7, which may be either a transmitter or a receiver, is connected by means of transmission line 8 to the terminal of the antenna and the adjacent terminal of the counterpoise. The remaining or "back" terminals of the antenna and counterpoise are connected together through a terminating impedance 9. As shown in Fig. 2 the horizontal antenna-counterpoise system is spaced preferably a half-wave length or more above the ground. Such spacing improves the discrimination against received horizontally propagated waves.

Any type of high frequency transmission line may be suitably employed with the antenna-counterpoise system disclosed in the drawing. In practice it has been found that the form of transmission line most suitably employed depends upon whether the antenna is used as a transmitting or a receiving system. For example, when the antenna is used for transmitting purposes, a matched line which may include impedance transformers gives very satisfactory results; and when employed for receiving purposes a concentric line including a balanced coupling transformer is a suitable form. The balanced line such as is used in connection with receiving systems suppresses reradiation from the line and also to a great extent cancels interfering waves absorbed by the vertical portion of the line.

The basic theory underlying the operation of the antenna system as shown in Figs. 1 and 2 is set forth in our British Patent No. 353,517 the reception or transmission of the horizontally polarised component being assumed instead of the vertically polarised component. The counterpoise comprising conductors 3 and 4 in a sense simulates the ground associated with the vertical Vee-type antenna. Because of the compensatory effect of ground reflection substantially no reception or transmission occurs in a horizontal plane and maximum reception, as shown by arrow C, and maximum transmission, as shown by arrow D, each occur at a high angle to the plane of the antenna and the ground. Maximum reception occurs in the vertical plane including arrow A Fig. 1 and maximum transmission similarly occurs in the vertical plane including arrow B. This compensatory effect is related to the fact that the horizontally polarised component with which this invention is concerned undergoes a phase reversal on reflection. This is not true of the vertically polarised component that is made use of in the operation of the otherwise similar vertical antenna of our British Patent No. 353,517. This accounts for the difference in the angles of fire between the horizontal and vertical antennae, a difference which would not result merely from applying the theory of said British Patent No. 353,517 assuming a 90° rotation of the antenna.

The terminating impedance 9 may be a pure resistance or a tuned circuit comprising capacity and inductance or both. If the length of each member of the antenna and counterpoise is equal to an odd multiple greater than one of a quarter-wave length, a terminating impedance equal substantially to the antenna surge impedance will produce uni-directivity; and if the length of each of these members equals an even multiple greater than two of one-quarter wave length a terminating impedance equal to the product of the antenna surge impedance and the cosine of the angle whose sides are formed by the member and its projection on the vertical plane of propagation will render the system unilateral. For antennae having members of different length than those just mentioned a terminating impedance comprising a resistance and either a capacitive or an inductive reactance, as conditions may require, may be employed to produce a uni-lateral effect. It has been found in practice that in transmitting antennae an iron wire resistance is suitable for dissipating the large amount of energy which would otherwise be radiated in a direction opposite to the desired direction; and in receiving systems a carbon resistance is suitable for dissipating the relatively small amount of energy received from the rear or undesired direction.

The horizontal Vee-type antenna described herein possesses distinct advantages over other types of antennae commonly employed. First of all, as is well known in long distant radio communication, the horizontally polarised component of a radiated wave is much stronger at the receiving point than the vertically polarised component and from this viewpoint the horizontal antenna, which absorbs horizontally polarised components, absorbs a greater amount of

energy than a vertical type antenna. Moreover, since very little energy is absorbed by the horizontal antenna of the invention from horizontally propagated waves, undesired pick-up from automobiles and other interfering sources positioned at points relatively near to the receiving antenna is greatly reduced. This feature does not affect the efficiency of the antenna for receiving the desired wave since, as pointed out before, the desired wave is received at a relatively high angle with respect to the ground. In this connection it should be noted that in the case of the vertical Vee-type antenna maximum radiation and reception occur in a horizontal plane, that is, at a zero angle with respect to earth. The high angle obtained in the horizontal Vee is particularly useful in long distance transmission and reception. Still another advantage of the horizontal over the vertical type of antenna is that the horizontal type may be cheaply constructed in view of the fact that the supporting poles are relatively small.

Having now particularly described and ascertained the nature of our said invention and in what manner the same is to be performed, we declare that what we claim is:—

1. A modification of the antenna claimed in our British Patent No. 353,517, characterised in this, that a substantially horizontal antenna comprises a V-shaped conductor, said conductor comprising two members each having a length substantially equal to one-half wave length of the desired wave plus the projection of the member on the vertical plane of wave propagation.

2. An antenna comprising two conductors positioned in a substantially horizontal plane, one conductor extending toward and the other away from a distant co-operating station, said conductors being of equal length and having a common terminal, the length of each conductor being substantially equal to one-half wave length of the desired wave plus the projection of the conductor on the vertical plane.

3. An antenna comprising two similar V-shaped conducting members as claimed in claim 1 or 2, with their open angles directed toward each other, said V-shaped members both lying in the same general horizontal plane, a transmission circuit being connected to a terminal of one V-shaped member and to the adjacent terminal of the second V-shaped member, and a terminating impedance being connected to the other terminals of the V-shaped members.

4. An antenna according to claims 1 or 2 connected to a counterpoise, said counterpoise comprising a V-shaped conductor of substantially the same dimensions and configuration as said antenna and lying in the same horizontal plane but having its open angle presented in an opposite direction.

5. An antenna arrangement substantially as described and as illustrated in the accompanying drawings.

Dated this 11th day of November, A.D. 1931.

ERNEST HEY,
Chartered Patent Agent,
Agent for the Applicants,
Telephone Building, The Hyde, Hendon, N.W.9.

Redhill: Printed for His Majesty's Stationery Office, by Love & Malcomson, Ltd.—1933.

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FIG. 1.

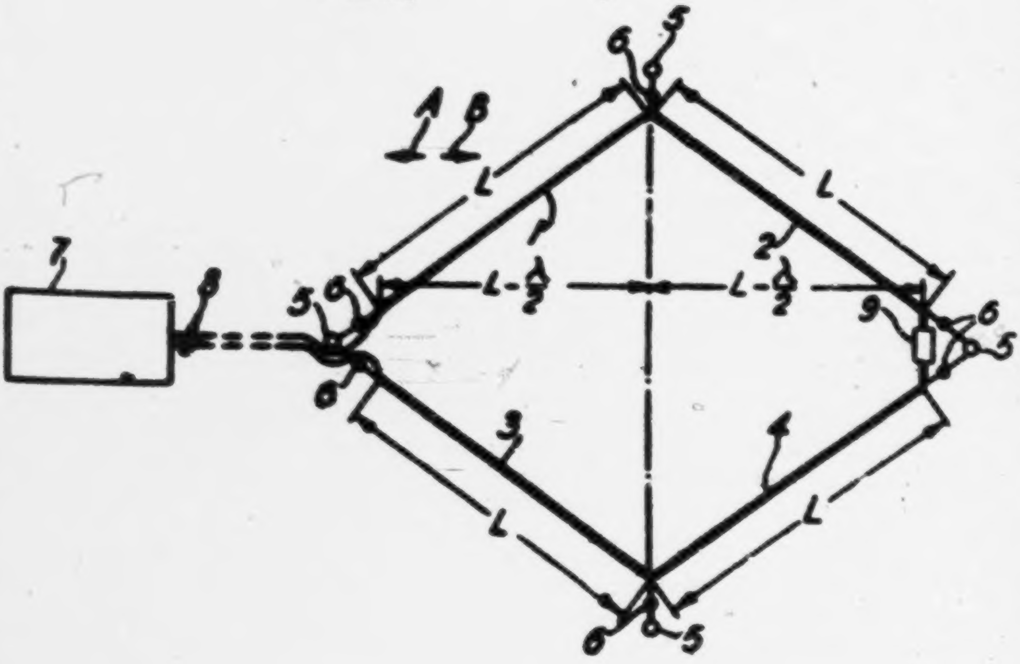
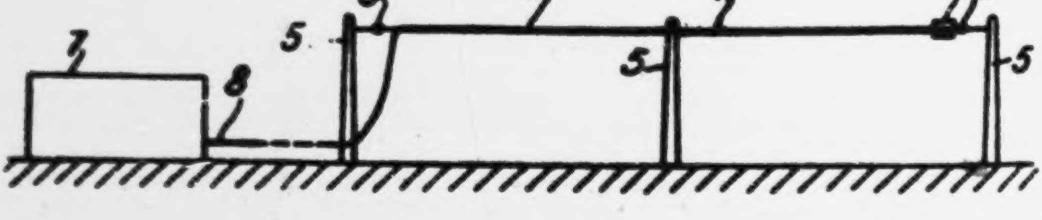


FIG. 2.



[fols. 829-842] PLAINTIFF'S EXHIBIT No. 42

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DIRECTIVE ANTENNA SYSTEM

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FIG. 2.

VECTOR DIAGRAM FOR ANTENNA OF FIG. 1.

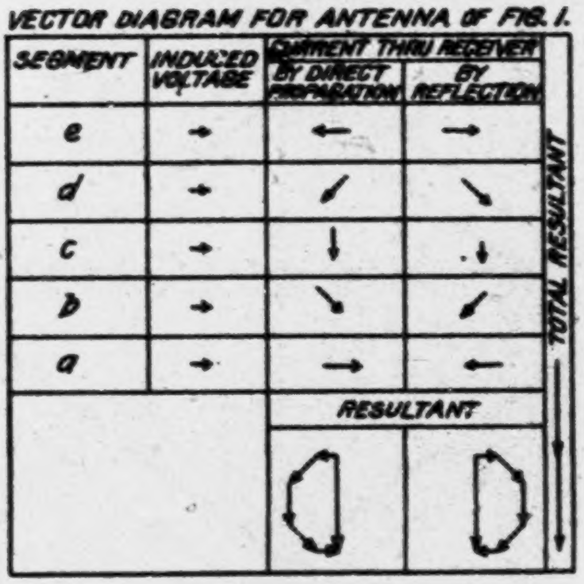


FIG. 1.

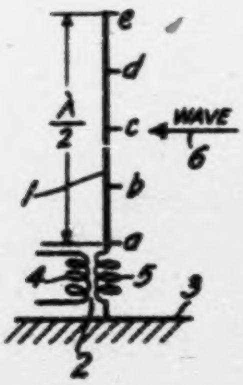


FIG. 4.

VECTOR DIAGRAM FOR ANTENNA OF FIG. 3

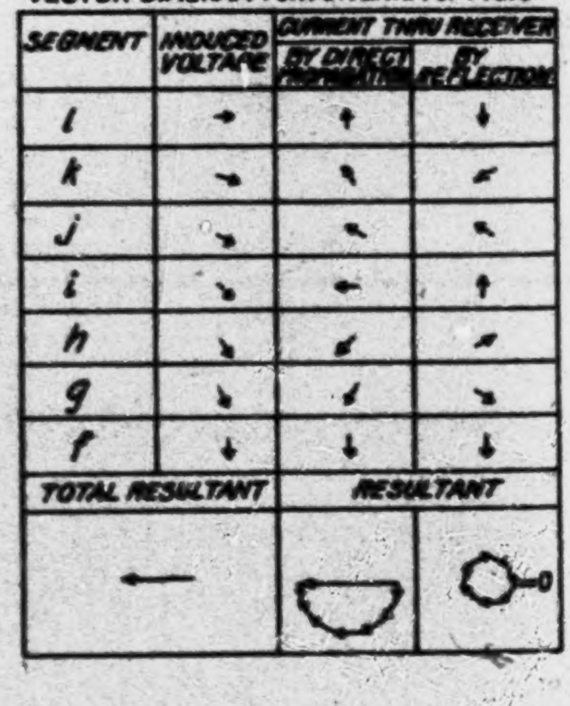
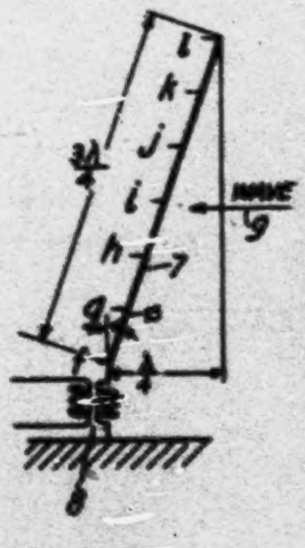


FIG. 3.



INVENTOR
E. BRUCE
BY Guy T. Mon[...]
ATTORN[...]

Feb. 28, 1933. E. BRUCE 1,899,410

DIRECTIVE ANTENNA SYSTEM

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FIG. 5.

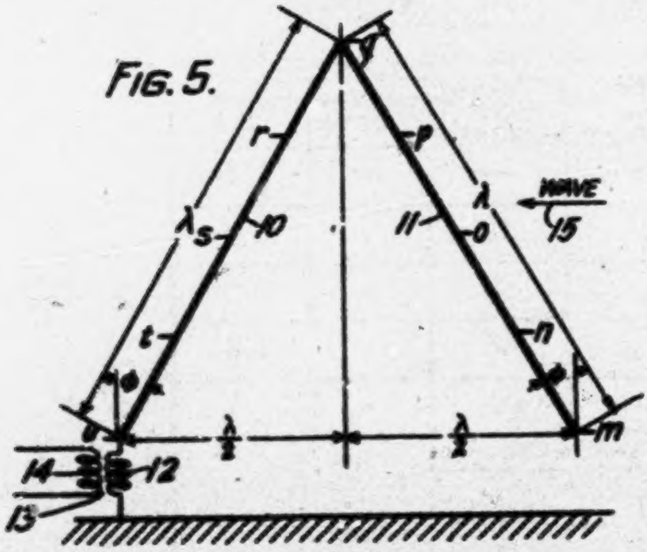


FIG. 6.

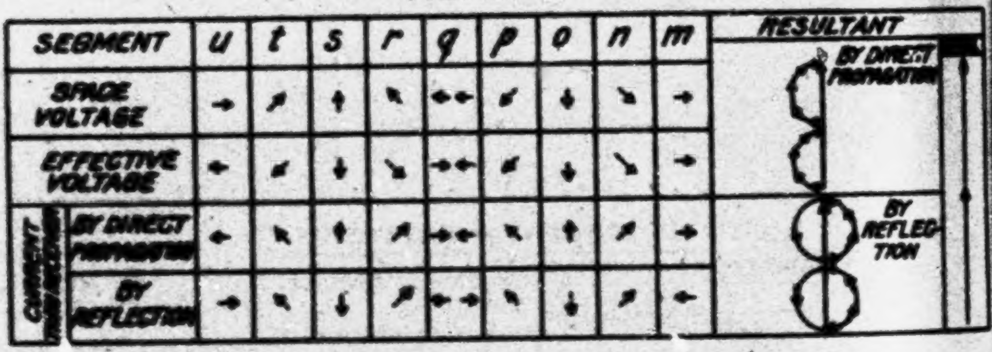


FIG. 7.

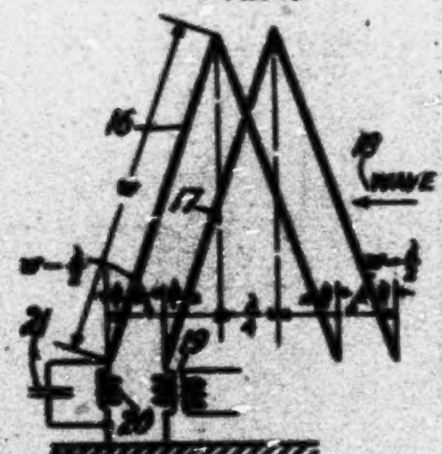
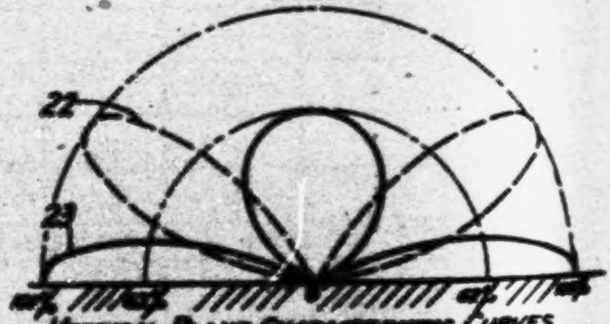


FIG. 8.



VERTICAL PLANE CHARACTERISTIC CURVES

$w = \lambda$

---- $\phi = 0°$

—— $\phi = 30°$

INVENTOR
E. BRUCE
BY Guy T. M...
ATTORNEY

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DIRECTIVE ANTENNA SYSTEM

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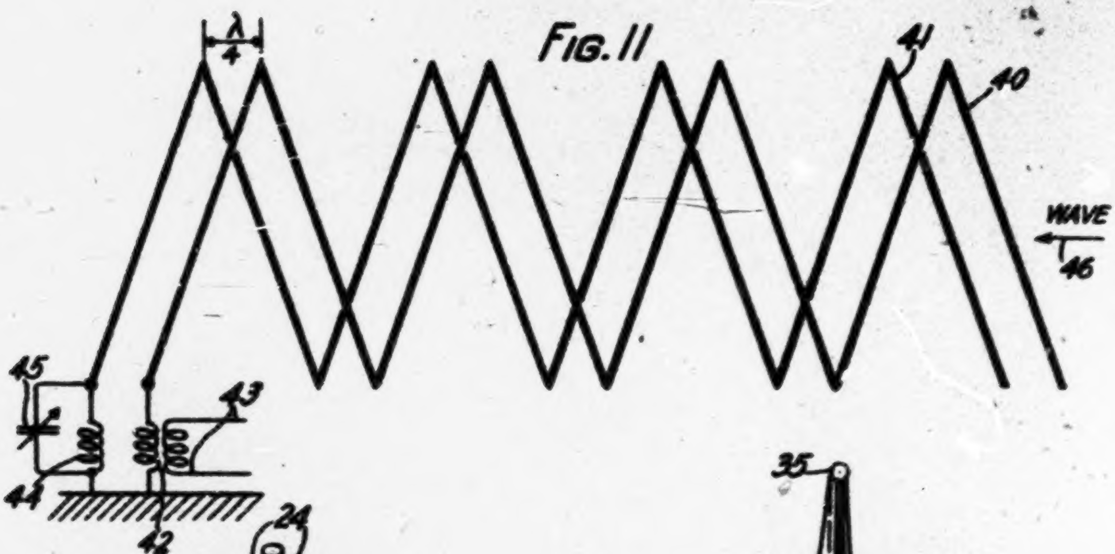

FIG. 11

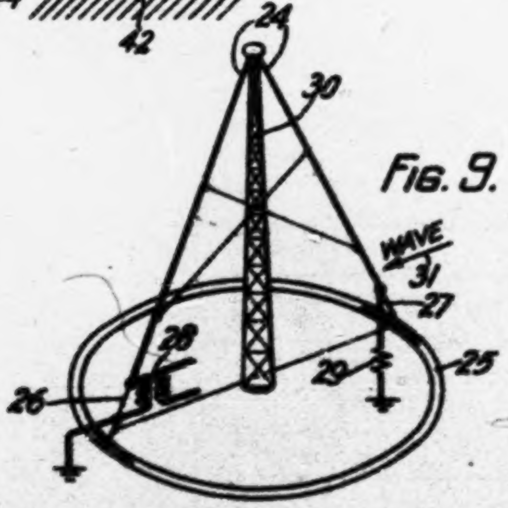

FIG. 9.

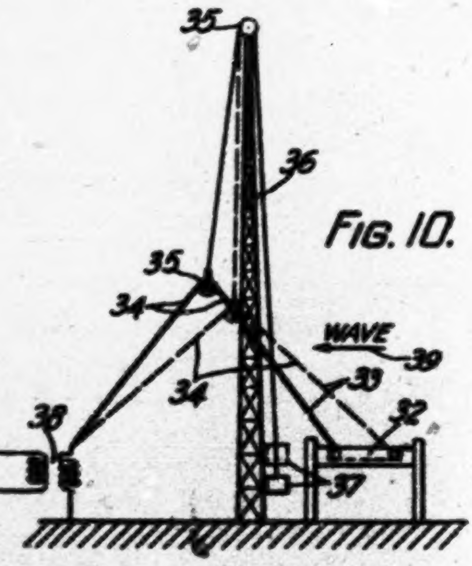

FIG. 10.

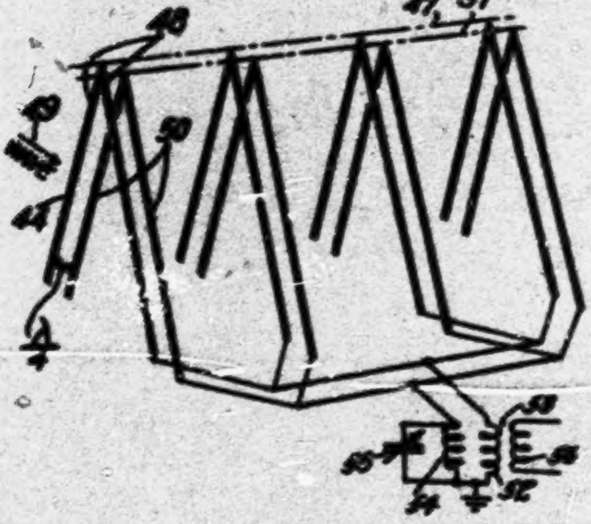

FIG. 12.

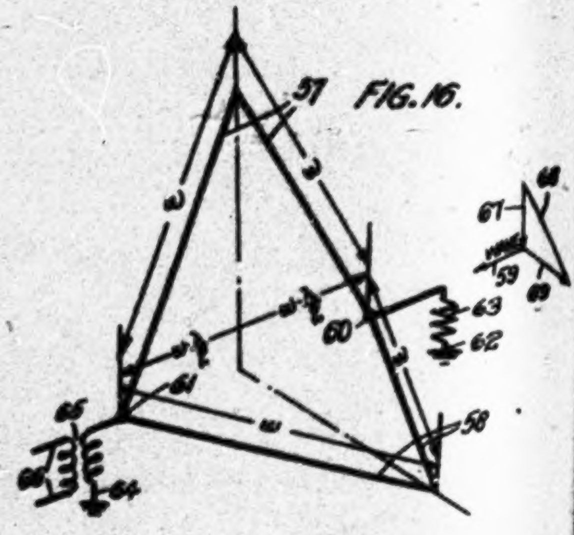

FIG. 16.

INVENTOR
E. BRUCE
BY Guy T. Morris
ATTORNEY

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FIG. 13.

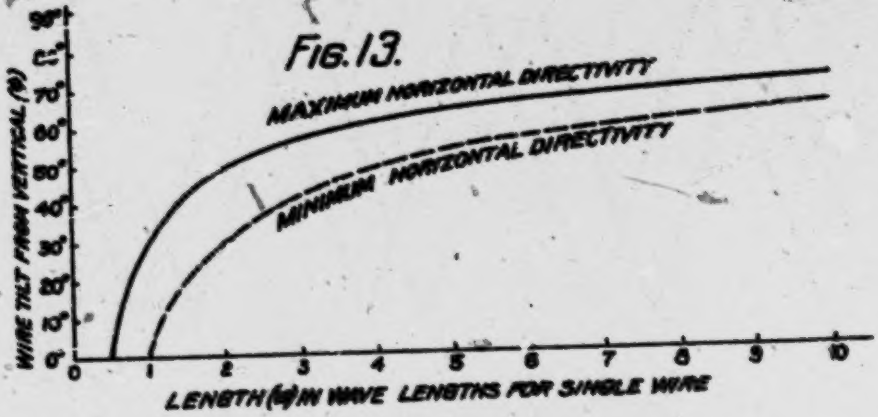


FIG. 14.

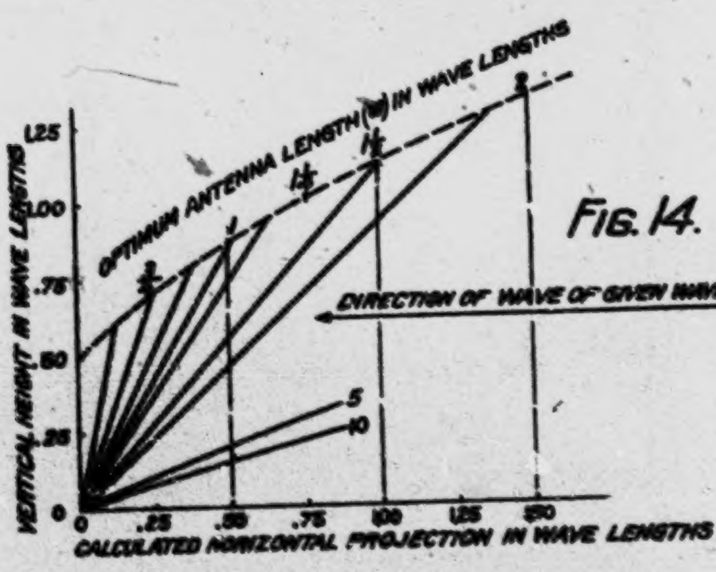
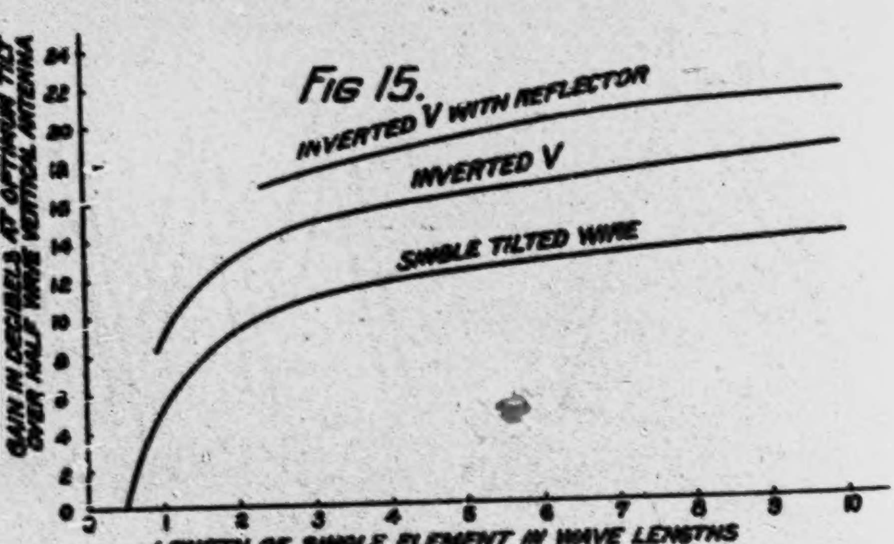


FIG 15.



INVENTOR
E. BRUCE
BY Henry T. Morris
ATTORNEY

Patented Feb. 28, 1933 1,899,410

UNITED STATES PATENT OFFICE

EDMOND BRUCE, OF RED BANK, NEW JERSEY, ASSIGNOR TO BELL TELEPHONE LABORATORIES, INCORPORATED, OF NEW YORK, N. Y., A CORPORATION OF NEW YORK

DIRECTIVE ANTENNA SYSTEM

Application filed October 11, 1929. Serial No. 398,990.

This invention relates to aerial systems, and more particularly to directive antennæ for use in such systems.

An object of the invention is to render a directive antenna capable of effective operation over a considerable range of wave lengths. Another object of the invention is to increase the receiving effectiveness of an antenna. An additional object of the invention is to enable an antenna to have a desirably sharp selectivity both in a vertical plane and in a horizontal plane. A still further object is the reduction of fading in wave propagation.

It is well known that the most effective height for a simple vertical antenna with a ground connection at its lower end is one-half the wave length of the waves transmitted. This is because the elemental lengths of such an antenna absorb or emit, as the case may be, energies which conspire when superposed to yield a resultant that is greater in magnitude than may be had from a similarly excited similar antenna of shorter or longer length. It has been found, however, that the receiving effectiveness which is characteristic of a vertical half-wave length antenna may be retained and in fact enhanced by an increase in the length of the antenna accompanied by a definite tilt of the antenna toward or away from the remote cooperating sending station. The simple general rule is that the length of the tilted antenna should be equivalent to a half-wave length of the transmitted waves plus a length equal to the projection of the antenna on a plane parallel to the direction of the wave propagation. In the case of horizontally propagated waves and perfect ground, the length of the antenna should be equal to a half-wave length increased by the horizontal projection of the tilted antenna. If the ground is imperfect the length will be slightly different from the above.

It results also that in the case of a tilted antenna several wave lengths long, the effective response of the antenna varies but little with a considerable change in wave length of the transmitted waves, assuming that the energy of the transmitted waves and their direction of propagation remain unchanged. It is accordingly feasible to employ such an antenna in a system in which it is desirable or necessary to change wave lengths from time to time and this is an extremely important feature of the invention. It is also practical to combine the antenna with simple mechanical means for quickly changing the antenna tilt to the optimum angle simultaneously with a change in the wave length since, by this expedient, accommodation to different wave lengths of received waves may be achieved without change in length of the antenna or substitution of one antenna for another; and to combine the antenna with mechanical means for rotating the vertical plane of the antenna to the optimum position for radiating or absorbing energy.

Tilted antennæ constructed according to this invention readily lend themselves to various combinations and to use in arrays. Such an antenna suitably terminated exhibits a back-end effect which is relatively very small in comparison with its end-on directive selectivity.

Additional features of the invention and ends which it attains will be apparent from a perusal of the following specification taken in connection with the accompanying drawings in which;

Fig. 1 represents a vertical half-wave length antenna shown here merely for the purpose of explaining an incidental feature of the invention, Fig. 2 being a table showing in detail the vector currents for the antenna of Fig. 1;

Fig. 3 represents a three-quarter wave length antenna tilted at the optimum angle toward the incoming wave, Fig. 4 being a vector diagram for this antenna;

Fig. 5 illustrates an inverted V-type antenna comprising two tilted conductors or elements, Fig. 6 representing a vector diagram for such a system;

Fig. 7 is a double inverted V antenna comprising two single V-type antennæ;

Fig. 8 shows the vertical plane directional characteristic of a tilted single wire antenna and a vertical single wire antenna each one wave length long;

Fig. 9 represents schematically one system for combining an inverted V antenna section with means for rotating the vertical plane of the antenna to any desired direction;

Fig. 10 shows a single inverted V antenna section associated with means for changing the angle of tilt of each leg or element of the V section;

Figs. 11 and 12 represent, respectively, a unidirectional "end-on" and a unidirectional "broadside" antenna system each comprising an exciter and a reflector;

Figs. 13, 14 and 15 are curves for systems which employ the invention and are designed for a particular wave length. The curves in Fig. 13 show the relation between the angle of tilt of a single linear wire antenna and the length of the antenna in the cases of maximum and minimum horizontal directivity; the curve of Fig. 14 furnishes a means of determining the horizontal and vertical projections of different length antennæ, each tilted at the optimum angle for horizontal directivity; and the curves in Fig. 15 show the gain in decibels realized in using tilted antenna of the types and lengths indicated as compared to the results obtained with the half-wave vertical antenna; and

Fig. 16 illustrates two inverted V-sections positioned in different planes and having common terminals.

Referring to Fig. 1, the reference numeral 1 designates a vertical half-wave length antenna which is associated with a radio translation device, such as a receiver or transmitter, by means of transformer 2 having windings 4 and 5. The lower terminal of the antenna is connected through winding 5 to the ground 3.

Assuming the direction of the incoming wave to be as shown by the arrow 6 the wave impinges on all elements such as *a*, *b*, *c*, *d* and *e* of the vertical antenna 1 at the same instant and therefore the various induced voltages are in phase with each other and may be assumed to have the directions indicated in the second column of Fig. 2. The current produced by the voltage in segment *e* and directly propagated to winding 5 will require a time corresponding to a half cycle to travel from segment *e* to the coil 5. Similarly, the current directly propagated from point *d* will require a time corresponding to three-eighths of a cycle to reach winding 5 and currents directly propagated from points *c*, *b* and *a* will require a time corresponding to one-fourth, one-eighth and zero cycles, respectively, in arriving at winding 5. Assuming counter-clockwise rotation as positive or advancing the individual currents in winding 5, at the instant under consideration, are consequently retarded in respect to their producing voltages by an amount equivalent to the antenna length separating winding 5 from the respective segments. In column three of the table of Fig. 2 this is represented by means of small arrows which indicate direction only, and not current magnitudes. Summing up the individual vector currents directly propagated, it will be seen from the diagram at the bottom of the column of the table that the resultant is a maximum vector inasmuch as it is a diameter of the vector circle. Although this proof is based on a choice of spaced elemental portions, it is evident that the conditions in the antenna as a whole are fairly represented by such portions and therefore that the table indicates the resultant effect in the antenna as a whole.

The resultant reflected current is similarly determined. The conditions are as indicated in column four of the table. Current from the segment *e* has a reversal of phase on account of reflection from the open-ended antenna and therefore arrives at winding 5 at a time corresponding effectively to a full cycle after it originates and therefore, at any given instant, as measured at winding 5 it is retarded a full cycle in respect to the voltage *e*. Reflected current occasioned by voltage *d* travels an eighth of a cycle to the open end, is effectively retarded a half-cycle by reflection and then is retarded, by the half-wave antenna, another half-cycle before reaching coil 5. At the instant it arrives at winding 5 it is therefore retarded one and one-eighth cycles in respect to the voltage in segment *d*. The remaining vectors for the reflected currents are determined in a similar manner and their resultant is also a diameter of the vector circle as shown in the table. This last mentioned resultant, it will be observed, has the same direction as the resultant for the directly propagated current and consequently, both resultants for the antenna of Fig. 1 add or cooperate to give a maximum total resultant or, in other words, maximum horizontal directivity. The vectors are, of course, rotating and the directions shown by the arrows are relative only.

In connection with Fig. 1 it should be noted that if the vertical antenna were one wave length in height instead of one-half wave length, a minimum or zero total vector resultant would be obtained for waves propagated in a horizontal plane. A vertical antenna one wave length in height is therefore especially adapted to reject horizontal waves. Also, in comparing vertical antennæ and tilted antennæ constructed in accordance with the invention, a vertical half-wave antenna is a suitable standard of comparison inasmuch as it possesses a maximum horizontal directional characteristic.

In Fig. 3 the antenna 7 is three-quarter's of a wave length long and is connected through one winding of transformer 8 to ground. The other winding of transformer 8 may be connected to a transmitter or receiver but for purposes of this description it

will be considered as connected to a receiver. The antenna is tilted from the vertical at such an angle ϕ that the projection of the antenna on a plane parallel to the direction of the incoming wave, represented by the arrow 9, is one-half wave length shorter than the length of the antenna proper, that is, one-quarter wave length long for the antenna of Fig. 3. As explained vectorially below an antenna tilted at such an angle, termed herein the optimum angle for the given antenna length, possesses a maximum directional characteristic in the direction of the wave propogation. The small letters *f*, *g*, *h*, *i*, *j*, *k* and *l* represent small antenna segments spaced an eighth wave length along the antenna.

Referring to the table of Fig. 4, and to the induced voltage column particularly, it will be seen that the voltages simultaneously induced in the segments are of relatively different phase and in this respect the system differs from that shown in Fig. 1. This results from the fact that the part of the wave inducing the voltage in any one segment is 15° or $\frac{1}{24}$ of a cycle retarded in respect to that inducing the voltage in the segment immediately above. The various phase differences between the induced elemental voltages and their resulting currents through the transformer 8 are obtained in the manner already explained in connection with Fig. 2, the currents, as in Fig. 1, being always retarded in respect to their voltages with the exception of the current directly propagated from the lowest segment. A maximum resultant is obtained for the directly-propagated current and zero resultant for the reflected current as shown at the bottom of the table of Fig. 4.

In all antennæ tilted in accordance with this invention, the resultant of the directly-propagated current is a diameter of a vector circle. The resultant of the reflected current varies from zero, in the case of antennæ having a length equal to an odd quarter multiple of a wave length, to small values when the length is an even multiple of a quarter wave length; and as the even multiple increases the reflection resultant decreases. An antenna tilted as shown in Fig. 3 has a substantially unity front to back-end ratio which may be greatly increased, that is, the effects produced by waves propagated in a direction opposite to that indicated by arrow 9 may be practically eliminated by properly terminating the antenna. It has been found, for example, that if the single wire antenna is equal in length to an odd multiple, greater than one, of a quarter wave length, a terminating impedance equal substantially to the antenna surge impedance will produce unidirectivity; and, if the antenna length equals an even multiple, greater than two, of a quarter wave length, a terminating impedance equal to the product of the antenna surge impedance and the sine of the angle of tilt of the antenna from the path of propagation will render the system unilateral. The terminations, however, would not affect the reflection phenomena and would not change the characteristic illustrated in Fig. 4 since, for single wire tilted antennæ the resultant reflected current is zero as indicated in this figure. Stated differently, if the tilted antenna has a length equal to an odd multiple of a quarter wave length, and is terminated in an impedance equal to its surge impedance, the ratio of the front to back end reception or radiation is infinity. If it has a length equal to an even multiple of a quarter wave length and is similarly terminated, the ratio is small but this ratio increases as the length, that is, as the even multiple, increases and by changing the terminating impedance to a value equal to the product of the surge impedance and the sine of the angle of tilt, the ratio may be made infinite.

Compared to the standard half-wave antenna of Fig. 1 the transmission gain obtained in using the antenna of Fig. 3 results primarily from the fact that the latter is longer and more directive than the former. The vertical antenna receives horizontally propagated waves equally from all directions whereas the tilted antenna favors two opposite directions, the directivity diagram resembling a figure eight. Compared to a vertical three-quarter wave length antenna the final resultant for the tilted antenna of Fig. 3 possesses no reflected component whereas the resultant for the vertical antenna includes a reflected as well as a directly-propagated component.

In both Figs. 2 and 4 the directly-propagated and reflected current vectors for the extreme top segment are opposite in phase to those for the extreme bottom element. This condition is necessary in all cases for maximum results. In other words, the antenna should be tilted toward or away from the incoming wave in such a manner that current originating at the top element will arrive or pass through the receiver a half-cycle later than that simultaneously originating in the bottom element. When this condition is fulfilled the antenna will be a half-wave longer than its projection on a plane parallel to the direction of the wave propagation and its angle with the projection will be the optimum one as heretofore defined.

In Fig. 5 another embodiment of the invention is shown comprising two conductors 10 and 11 each tilted at the optimum angle ϕ for the desired waves and joined to each other so as to form an inverted V. For purposes of illustration the length of each conductor or element has been made equal to one wave length. As in Fig. 3, this length is a

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half-wave length longer than the projection of the element on a plane parallel to the direction of the propagation of the desired waves. The lower terminal of conductor 10 is connected to ground through winding 12 of transformer 13. Winding 14 of this transformer is connected to either a transmitter or a receiver. The antenna system shown in this figure possesses a bidirectional characteristic but it may be made unidirectional by properly connecting the conductor 11 to ground through an impedance at "*m*". The small letters *m* to *u* designate infinitesimal segments located along conductors 10 and 11, the adjacent segments being a quarter-wave length apart. The arrow 15 indicates the direction of the incoming wave.

Referring to Fig. 6 a vector diagram for the structure shown in Fig. 5 is shown. The induced or spaced voltages at the elemental segments *m* to *u* are represented in the top row of arrows. As shown in this row of arrows, the voltage induced in segment *n* is one-eighth of a cycle retarded over that induced in segment *m* and similarly the voltages induced in the remaining elemental segments are one-eighth of a cycle behind that induced in the segment immediately adjacent at the right. The second row of arrows from the top represent the effective or wire voltages at the same elemental points. The effective (as regards the effect on winding 12) voltages present in conductor 10 as, for example, in segments *q* to *u* are opposite in phase to those induced in conductor 10 and cooperate with, rather than oppose, the effective voltages in the other of the two conductors. This is true since, so far as concerns their joint effect in winding 12, the direction of the elemental voltages in conductor 10 are reversed with respect to the voltages in conductor 11 by the bend or apex of the antenna.

The manner of determining the phase relation between the voltages and both the directly-propagated and the reflected currents passing through winding 12 has been described in connection with Figs. 1 and 2 and will be outlined only briefly here. The directly-propagated current produced by voltage *m* will arrive at coil 12 two complete cycles behind the elemental voltage *m* producing it, inasmuch as the antenna is two wave lengths long. Current resulting from voltage *n* travels a distance equal to one and three-fourth wave lengths along conductors 11 and 10 and of course passes through winding 12 one and three-quarter cycles behind voltage *n*. Similarly, the directions of the other elemental directly-propagated and reflected currents may be determined bearing in mind that current flowing to the open end is reversed on reflection and therefore effectively retarded a half-cycle. For example, reflected current travelling from *n* arrives at winding 12 in opposite phase relation to the directly-propagated current; and current originating at *n* travels one-fourth of a wave length, corresponding to a retardation of 90°, to the free end, is retarded 180° by reflection and then travels two full wave lengths, corresponding to a retardation of 720°, to coil 12. The summations of both the direct and reflected currents are shown at the right of the table in Fig. 6. It should be observed in regard to the reflected current that the resultant for each of conductors 10 and 11 for progressively increasing numbers of segments travels 540° or one and one-half times around the vector circle and finally assumes the same direction as the resultant for the other conductor. This double resultant is added to the double resultant obtained for the directly-propagated current to give the total resultant shown at the extreme right in Fig. 6. For waves propagated in a direction opposite to that shown in this figure the direct and reflected components will be similar but opposite in direction to the reflected and direct components, respectively, shown in the figure. The total resultant will, of course, also be opposite in direction to that shown in the figure. The system of Fig. 5 is therefore bilaterally directive and equally responsive to waves propagated in both directions.

In Fig. 7 a unidirectional receiving system is shown comprising two inverted V antennas 16 and 17. Antenna 16, the reflector, is spaced one-fourth of a wave length farther away from the wave source and in the same vertical plane as antenna 17, the exciter. The arrow 18 indicates the direction of the wave propagation. Each tilted conductor or element has a length "*x*" wave lengths long and is positioned at the optimum angle ϕ for horizontal directivity so that the horizontal projection of each element is a half-wave length shorter than the element length or $x-\frac{1}{2}$ wave lengths. Reference numeral 19 represents a transformer utilized for connecting the exciter 17 to the receiver. Numerals 20 and 21 refer, respectively, to an inductance coil and a condenser employed for properly terminating the reflector 16.

Unidirectivity is achieved by means of the reflector in a manner which is familiar to those skilled in the art. The voltage induced in conductor 16 by the desired waves is retarded one-fourth of a cycle in respect to that induced in conductor 17. Since the field reradiated from conductor 16 is opposite in phase to that of the space field immediately adjacent and since there is a quarter-wave length spacing between the reflector and exciter, energy from the inverted V antenna 16 induces a voltage in antenna 17 in phase with the voltage induced in the latter. The resulting currents therefore re-

sist each other and reception in this direction is a maximum. Waves from the opposite direction, however, induce a voltage in the reflector 16 which leads that simultaneously induced in the exciter 17 by a quarter cycle. Because of the 180° phase change due to reradiation and the quarter-wave length spacing, the voltage induced in the exciter 17 by energy from the reflector 16 is opposite in phase to that then being induced in the exciter. Currents induced by energy from this undesired direction are therefore effectively suppressed.

In Fig. 8 polar directional characteristic curves in the vertical plane which have been mathematically calculated are shown for a linear receiving antenna having a length equal to one wave length and connected to a perfect ground. The dotted line curve 22 containing two loops represents the characteristic when the antenna is vertically positioned and the full line curve 23 when the antenna is tilted 30° from the vertical in a vertical plane which includes the point of propagation. Along the horizontal axis the distance designated one hundred per cent represents the maximum desired current obtainable theoretically for this system. When the antenna is tilted in any other vertical plane the desired current will be less than the maximum just mentioned. A study of these curves reveals the fact that there is practically no reception in the horizontal direction when this antenna is in vertical position whereas when it is tilted 30° in the path of the incoming wave, there is a maximum reception of desired waves. Furthermore, the position of the minor lobe for the tilted antenna indicates that this antenna has a very good characteristic for waves propagated vertically as well as horizontally. In other words it has a high angle of response and therefore is particularly adapted for minimizing static if static is more intense at angles relatively close to the earth's surface as it is believed to be. For the same reason the absorbed energy including that reflected by the Heaviside layer arrives over comparatively few transmission paths with the result that fading is materially reduced. The antenna represented possesses a bidirectional characteristic but as explained heretofore it may be made unidirectional by either the use of a reflector or a proper terminating impedance.

In Fig. 9 an inverted V type antenna 24 such as heretofore described is shown arranged so that the vertical plane of the antenna may be changed to any desired direction. The particular arrangement shown in this figure is illustrative only, and it should be understood that any suitable scheme for changing the direction of the vertical plane so as to include therein a distant transmitting or receiving station could be utilized in place of the rotating means shown here.

The system schematically shown in this figure comprises a circular track 25 located in a horizontal plane and connected through insulators 26 and 27 to both lower terminals of the inverted V. One terminal is grounded through one winding of transformer 28 which is associated with a translation system such as a transmitter or receiver. The other terminal is connected through a terminating impedance 29 to ground for the purpose of obtaining a unidirectional characteristic. The plane of the antenna may be rotated about the supporting tower 30 in either direction, the antenna conductors being kept in the same plane by means of suitable guy wires as shown. The antenna proper functions the same as the one shown in Fig. 5 and in addition thereto it is unidirectional and adjustable to the optimum plane for transmission or reception. It is shown in the drawings in the optimum position for receiving waves propagated in the direction indicated by the arrow 31.

In Fig. 10 one scheme of adjusting or changing the tilt of the antenna to the optimum angle ϕ for transmitting or receiving waves of any given wave length within certain limits is illustrated. The reference number 32 represents a horizontal track suitably supported and along which the conductor or element 33 of the inverted V type antenna 34 may be moved. The antenna is supported by a pulley 35 which in turn is supported by a pole or tower 36 and connected to a counterweight 37 so that when the conductor moves from the position shown by the full line to the position shown by the dotted line the combination of the pulley and counterweight cooperate to maintain each element of the antenna 34 equal in length and the angle of tilt of each element equal to that of the other. The antenna is connected to ground through transformer 38 which is connected to a receiver for receiving waves from the direction shown by the arrow 39. A transmitter could, of course, be used on this system in place of the receiver. If each side of the inverted V is several wave lengths long the apex of the V moves through a comparatively small distance as will be evident from the description given below of the curve of Fig. 13. The scheme used in Fig. 10 could of course be combined with that used in Fig. 9 so that an antenna system could be constructed which would be adjustable to different optimum angles and at the same time capable of being rotated to any desired direction for maximum directivity. Such a system would be especially suitable for use on boats and aircraft and in places where it is impractical to construct an antenna such as shown in Figs. 11 and 12 to be described.

Figs. 11 and 12 illustrate, respectively, an

"end-on" and a "broadside" antenna array of inverted V type antenna units of the invention. The "end-on" array and transmission system shown schematically in Fig. 11 comprises an exciter 40 and a reflector 41 each of which in turn comprises four inverted V sections, constructed in accordance with the invention and connected electrically to each other as shown. Practically any number of sections may be utilized, the number illustrated being arbitrarily chosen. Both the exciter and reflector are arranged in the same vertical plane with each other and with the distant cooperating station, and each reflector section is one-quarter of a wave length farther away from the distant station than its corresponding exciter section. The exciter is conductively connected through a transformer 42 to ground and inductively associated with a transmission line 43 to a translation device. The deflector is grounded through an impedance comprising coil 44 and condenser 45. The arrow 46 indicates the direction of the wave. The system shown in Fig. 11 is particularly suitable for use where considerations of ground space are not of primary importance. It possesses a very sharp unidirectional characteristic which may be greatly improved by properly choosing the number of the sections or inverted V antennae.

In Fig. 12 a broadside antenna arrangement is schematically shown in perspective. It comprises an exciter row 47 of inverted V sections, such as 48, all the apexes of which are in a plane perpendicular to the direction of the wave propagation, represented by the arrow 49. The sections are spaced from each other the proper distance which, for a given number of sections, will produce the sharpest unidirectional characteristic. In the same plane with each exciter section and one-quarter of a wave length farther away from the distant station is another inverted V type section, such as 50. These sections form a row 51 which comprises the reflector. Both the exciter and the reflector may consist of any number of sections and are not intended to be limited to the number shown on the drawing.

The transmission system shown in Fig. 12 is designed so that current flowing from each of the exciter sections to the winding 52 of transformer 53 traverses a distance equal to that which is traversed by currents flowing from the remaining exciter sections. Similarly, in the transmission system shown associated with the reflector sections, the current flowing from each reflector section to ground through the terminating impedance comprising coil 54 and condenser 55 traverses a distance equal to that traversed by the current flowing from the other reflector sections. The transmission system therefore does not affect the phase relation between the currents of the various sections. Winding 56 of transformer 53 is connected to a receiver.

The operation of the system shown in Figs. 11 and 12 is similar to that of the well known end-on and broadside arrays, respectively. When the end-on system is used for receiving purposes the energy absorbed in each section is serially combined with that absorbed in the other sections, and certain sections serve as a transmission line for energy absorbed in other sections. When the broadside array of Fig. 12 is used for receiving purposes the corresponding elements are simultaneously energized by the incoming wave and the sections are in a sense parallel to each other. A more detailed description of the end-on and broadside systems may be found in the applicant's copending applications Serial No. 173,833, filed March 9, 1927 and Serial No. 235,464, filed November 25, 1927, respectively. In both systems the vector resultant for each section effective at the transformer possesses the same direction as the other sections. Both systems may, of course, be employed for transmitting purposes with the same degree of success.

Referring to Fig. 13 two curves are shown, one of which serves as a means of determining the tilt from the vertical in the vertical plane including the distant station for different lengths of a linear antenna for the condition of maximum horizontal directivity and the other of which similarly determines the tilt for minimum horizontal directivity. Both curves possess a relatively flat characteristic for antenna lengths greater than five wave lengths. An examination of the curve for maximum horizontal directivity shows that the angle of tilt for an antenna five wave lengths long is 64° approximately and one ten wave lengths long is 72° approximately. Because of this small difference of 8° approximately, it is apparent that an antenna five wave lengths long and tilted the mean of the above optimum angles that is, 68°, toward the incoming wave would be suitable for use over a frequency range in which the high frequency is double that of the low. These curves therefore disclose one of the important features of the invention, namely, that a tilted antenna is particularly well adapted for use over a comparatively large frequency range. Also, it may be seen from a comparison of the two curves that an antenna tilted for maximum horizontal directivity may easily be adapted for minimum horizontal directivity because of the small difference, for an antenna of given length, between the optimum angles for maximum and minimum directivity.

From the curves in Fig. 14 the horizontal and vertical projections of antennae tilted at various optimum angles may easily be determined. The curve also illustrates in an-

other way the fact that for every antenna above five wave lengths long there is little difference in the various optimum angles and that an antenna several wave lengths long and tilted in accordance with the invention is admirably suited for use for several different frequencies.

From the curves in Fig. 15 the gain realized in using a single tilted wire, an inverted V antenna, and a double inverted V antenna of various lengths over the standard half-wave vertical antenna may be determined. As pointed out before, part of the gain obtained is due to the increased length employed in the tilted antenna as compared to the vertical half-wave standard and part is due to the fact that the antenna radiation resistance is decreased through the sharper directivity. Curves for the different types of arrays illustrated in Figs. 11 and 12 have been omitted from the drawing. It is sufficient to say that such arrays obviously possess greater transmission gains than that of the single sections whose gain over the standard are shown in Fig. 15.

In Fig. 16, two inverted V-sections 57 and 58 each constructed in accordance with the invention, are illustrated, one being disposed in a vertical plane and the other in a horizontal plane. The two sections are joined at the common extremities or terminals 60 and 61. The length w of each leg of the antenna is a half wave length longer than the projection of the leg on the path of the wave propagation designated by numeral 59. Extremity 60 is connected to ground 62 through a terminating impedance 63 which, as explained above, is of such value as to render the system unilateral and which, as also explained above, in certain cases only is equal to the surge impedance of the antenna. The other terminal 61 is connected to ground 64 through the primary winding of transformer 65, the secondary of which is associated by means of line 66 with a receiver not shown on the drawings.

The operation of the system shown in Fig. 16 is apparent in view of the discussion given above with respect to the previously described figures. It should be noted, however, that the antennae 57 and 58 favor different components of the same wave. Antenna 57, for example, absorbs a maximum amount of energy from the vertical component 67 of the polarized wave 68 and substantially no energy from the horizontal component 69. On the other hand, antenna 58 absorbs a maximum amount of energy from the horizontal component 69 and little, if any, energy from the vertical component 67. Obviously the two antennae may be used jointly, as illustrated, or separately.

While the invention has been described in connection with certain specific embodiments it is clear that the invention may be suitably employed in many other embodiments, and it is not intended to limit the invention to those illustrated. For example, arrays comprising single tilted conductors such as illustrated in Fig. 8, and other double inverted V systems comprising a plurality of inverted V antennae lying in different planes with their apexes or extremities superimposed may well be employed.

What is claimed is:

1. An antenna comprising a conductor positioned at an angle greater than zero degrees and less than ninety degrees to a plane perpendicularly related to the path of propagation of a wave and having a length substantially equal to a half-wave length of the desired wave plus the projection of the antenna on the path of the propagated wave.

2. A directive antenna system comprising one or more linear conductors at least one of which is inclined with respect to the vertical and is equal in length to substantially a half-wave length of the desired waves plus its projection on the path of the said waves.

3. A transmitting antenna comprising a conductor inclined to the vertical to such a degree that its projection on the horizontal is substantially equal to a multiple of one wave length.

4. A radio antenna comprising a conductor inclined to the vertical to such a degree that its projection on the horizontal is substantially equivalent to one wave length, the antenna having a linear dimension substantially equal to a multiple of a half wave length.

5. An antenna comprising a tilted conductor having a length substantially equal to a half wave length of the desired waves plus the projection of the antenna in the path of the waves, a receiver connected to one terminal and a suitable terminating impedance connected to the other terminal of the antenna.

6. A directive antenna for receiving a plurality of desired waves comprising a tilted conductor having a length of the order of five to ten wave lengths of the longest desired wave and tilted in the plane of wave propagation at an angle of the order of 18° to 25° from the path of propagation.

7. A tilted antenna for receiving a plurality of waves having a length greater than substantially five wave lengths of the longest desired wave and tilted in the plane of wave propagation at an angle less than 25° from the path of propagation so that the radiant energies of various wave lengths within a desired range which are absorbed by its terminal segments yield oppositely directed effects substantially when one of the energies is superimposed upon the other, and a translation device associated with the antenna.

8. An antenna comprising two conductors each positioned at an angle greater than zero

degrees to the plane of polarization and each having a length equal to a half-wave length of the desired waves plus its projection in the path of the wave propagation, the uppermost terminals of said conductors being joined.

9. A V-shaped antenna section comprising one conductor tilted toward and another conductor tilted away from the incoming wave, said conductors being of equal length and having a common terminal, said length being substantially equal to a half-wave length of the desired wave plus the projection of the conductor in the path of the waves, and a translation device associated with said section at a conductor terminal thereof.

10. An inverted V-shaped antenna section comprising one conductor tilted toward and another conductor tilted away from the incoming wave, said conductors being of equal length and joined at the top, said length being substantially equal to a half-wave length of the desired wave plus the projection of the conductor in the path of the waves, a receiver connected to the lower terminal of one conductor, and a suitable terminating impedance connected to the lower terminal of the other conductor.

11. A directive antenna system comprising a plurality of V-shaped sections lying in the same plane with each other and with a distant cooperating station, one of the said sections being an odd multiple of a quarter wave length of the desired wave farther away from said distant station than the other of the said sections.

12. A double inverted V-antenna system comprising an inverted V-shaped exciter and an inverted V-shaped reflector, each comprising conductors tilted for maximum directivity, said exciter and reflector being in the same plane with each other and with the path of the desired incoming waves, the reflector being a quarter wave length farther away from the source of said waves than the exciter, a receiver connected to the exciter, and an impedance connected to the reflector.

13. A directive antenna system comprising a plurality of inverted V-shaped sections comprising conductors each positioned at an acute angle to the plane of polarization of the desired wave and each having a length equal to a half-wave length of the desired wave plus its projection on the path of wave propagation, said sections lying in different planes and having common terminals.

14. In combination, an inverted V-shaped antenna comprising tilted conductors, each having a length equal to a half wave length of the desired wave plus its projection on the path of wave propagation, said antenna being rotatably supported at its apex, and one terminal of said antenna being connected to a translation device and the other terminal to a terminating impedance.

15. In combination with one or more inverted V-shaped antenna sections each comprising oppositely tilted conductors, the length of each of which is equal to a half wave length of a desired wave plus the conductor projection on the path of said wave, means for changing the plane of the antenna section to any desired direction.

16. In combination with an inverted V-shaped antenna, means for changing the tilt of each conductor thereof an equal amount, the tilt of each conductor of the antenna being adjusted so that the difference between its length and its projection on the path of a desired wave equals substantially a half wave length of said wave.

17. In combination, an inverted V-shaped antenna the apex of which is adjustably supported and one terminal thereof movable in the path of the desired waves, the tilt of each conductor being adjusted so that the difference between its length and its projection on the path of a desired wave equals substantially a half wave length of said waves, a translation device connected to the other terminal of said antenna.

18. In combination, a plurality of inverted V-shaped antenna sections each comprising two conductors, means for rotating the vertical plane of at least one of the said sections, means for equally changing the tilt of the conductors to any desired angle, the tilt of each conductor being adjusted so that the difference between its length and its projection on the path of a desired wave equals substantially a half wave length of said wave, a receiver connected to one terminal and a suitable impedance to the other terminal of the said section.

19. An end-on unidirectional antenna array for receiving waves from a distant source comprising an exciter and a reflector lying in the same plane, said exciter and reflector each comprising a plurality of V-shaped antenna sections colinearly arranged and electrically connected, said sections comprising conductors tilted so that the length of each conductor is equal to its projection on the path of the received waves plus one-half wave length of said waves, each reflector section being positioned a quarter wave length farther away from said source than a corresponding exciter section, a receiver connected to the exciter, and a suitable terminating impedance connected to the reflector.

20. A broadside unidirectional antenna array for receiving waves from a distant source comprising an exciter and a reflector, said exciter and reflector each comprising a plurality of parallel V-shaped sections having conductors tilted so that the length of each conductor is equal to its projection on

the path of the received waves plus one-half wave length of said waves, each exciter section being in the same plane with a reflector section, the exciter sections being positioned an equal distance from said source and each reflector section a quarter wave length farther away from said source than its corresponding exciter section, a receiver associated with the exciter, and a suitable terminating impedance associated with the reflector.

21. An antenna comprising a conductor having a length substantially equal to an odd multiple of a quarter wave length of a given wave, said antenna being tilted at an angle such that its projection on the path of said wave is equal to the antenna length minus a half wave length, an impedance connected to one terminal of said antenna, said impedance being equal to the surge impedance of the antenna.

22. An antenna comprising a conductor having a length substantially equal to a multiple of a half wave length of a given wave, said antenna being tilted at an angle such that its projection on the path of said wave is equal to the antenna length minus a half wave length, an impedance connected to one terminal of said antenna, said impedance being equal to the product of the antenna surge impedance and the sine of said angle.

In witness whereof, I hereunto subscribe my name this 5th day of October, 1929.

EDMOND BRUCE.

PLAINTIFF'S EXHIBIT No. 43

RADIO CORPORATION
OF AMERICA
ENGINEERING DEPARTMENT
66 BROAD STREET
NEW YORK

Mr Taylor
Pl. ack & docket
for Mr Tunick
W.G.

PATENT DEPARTMENT
RECEIVED
File - I
JAN 9 1930
ANSWERED ________

January 8, 1930

To: Mr. H. G. Grover - Patent Attorney
From: Mr. C. H. Taylor

Re: Patent Disclosure

Dear Mr. Grover:

I am attaching hereto a Patent Disclosure submitted by Mr. P. S. Carter covering the description of a new type of directional antenna.

You will note that an antenna of this type is now under construction and will be used for the San Francisco circuit as soon as completed and if successful will be left in circuit for pre-commercial test carrying commercial traffic.

Yours very sincerely,

C H Taylor

Vice President - Engineering

844

653

Form 233 7044-12-28

RADIO CORPORATION
OF AMERICA
INTERDEPARTMENT CORRESPONDENCE

TO: Vice-President - Engineering
FROM: Mr. P. S. Carter

DATE January 7, 1930
FILE No. I

SUBJECT: Patent Disclosure
LOCATION:
REFERRING TO:

Dear Mr. Taylor:

Attached are two copies of a brief description of a new type of directional antenna. This is the antenna which we are building near the Development Building in order to have an antenna directed on San Francisco to be used for experiments. Some of the poles of the old horizontal harmonic antenna are being used for this job..

If this antenna system proves to be as good in practice as it looks theoretically, it will result in the saving of a very large number of costly supporting structures.

Yours very truly
P. S. Carter
P. S. Carter

PSC/MVN
Cc Mr. H. H. Beverage
Mr. C. W. Hansell

IMPROVED TYPE OF DIRECTIONAL ANTENNA

The antenna system which I shall describe has been in mind several months but was not analyzed in detail until recently. It was written up beiefly in my notes of November 29, 1929 and disclosed to Mr. Hansell on the same date.

This system is, without doubt, the simplest and cheapest of any system yet devised, giving the same degree of concentration of radiated energy. After a fairly complete analysis, based upon principles which have all been proved to be sound in actual practice such as with the harmonic antenna, I have plotted the characteristics for both the horizontal and vertical planes in both polar and rectalinear coordinates. These are shown on sheets ~~A, B, C, and D~~ attached. Comparison of these curves with similar curves for the harmonic wire antenna will show that one unit of this improved system gives a concentration which is of the same order as two bays of the horizontal harmonic wire antenna. The horizontal harmonic wire antenna requires the use of 16 masts whereas this system requires only 6. In this improved system, the mechanical and electrical difficulties due to staggering are eliminated as all wire ends are parallel. Also, special devices for elimination of radiation from feeder jumpers, are unnecessary as the system is fed in a similar manner to the standard method of feeding a half wave dipole, the feeder system of which cannot radiate.

DESCRIPTION OF SYSTEM

The fundamental unit of this system consists of two wires (each longer than one half wayelength and preferably of a length equivalent to several wavelengths) fed from a transmission line in a manner such as shown in Fig. 1. It is essential that the angle included by the "V" be of a definite value determined from the length of the "V" according to a certain law which will be given in connection with the discussion of the technical principles involved. When the length of each wire is 8 wavelengths, this angle must be 35 degrees. The power distribution in the plane of the wires (normally the horizontal plane) is as shown in Fig. 2.

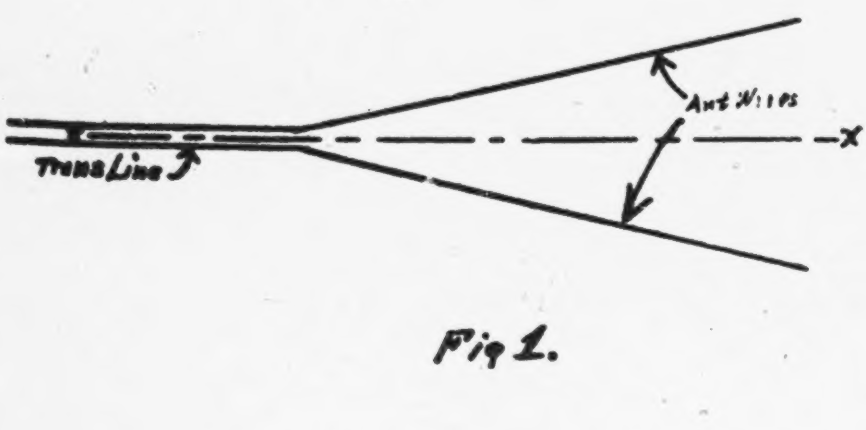

Fig 1.

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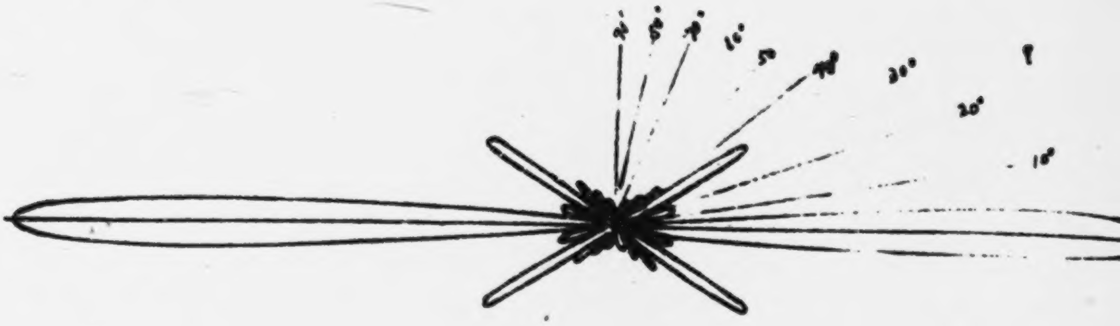

Fig. 2.

In order to prevent radiation vertically upward and downward and thus further increase the concentration in the desired direction, a duplicate system is placed one half wavelength or more above or below the first system and fed in the same phase. This is shown in Fig. 3.

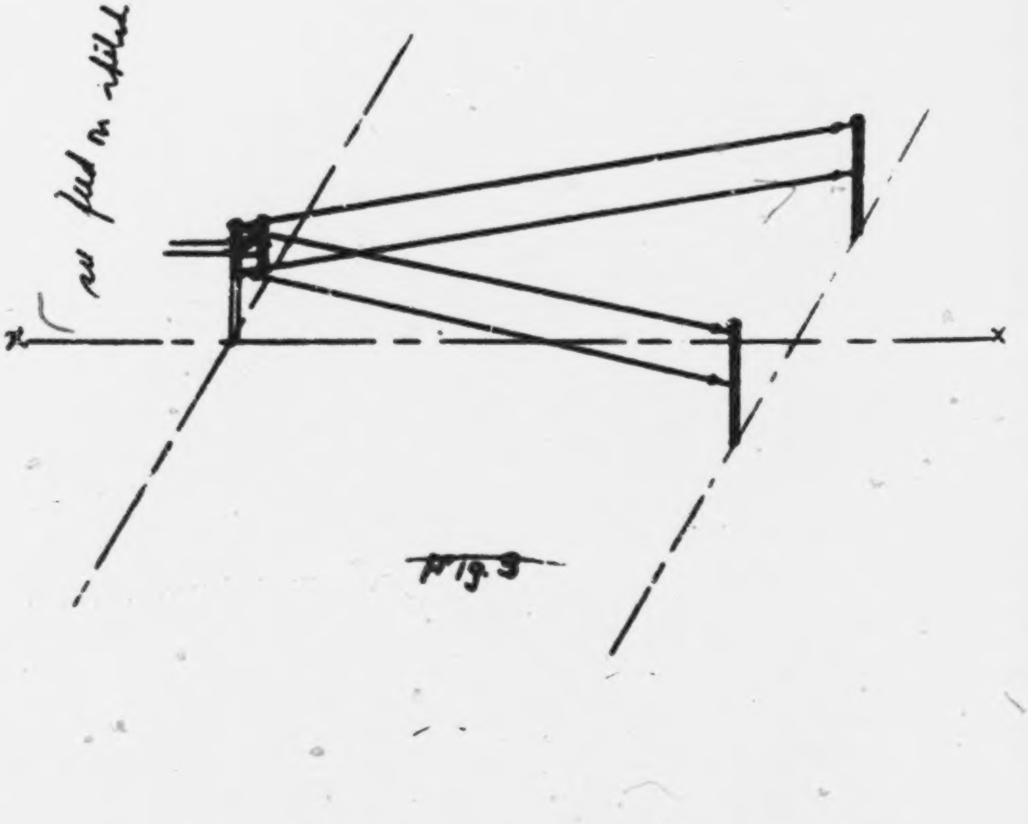

Fig. 3

In the horizontal plane, the power distribution of the system Fig. 3 is the same as shown in Fig. 2. In order to further concen-
te the radiated energy and to make the system unidirectional, a
plicate system to that of Fig. 3 is set up at a distance along the
ne x x equal to an odd number of quarter wavelengths. The second
stem is fed in either leading or lagging quarter phase depending
on whether it is desired to transmit in one direction or the reverse.
e complete single unit is shown in Fig. 4.

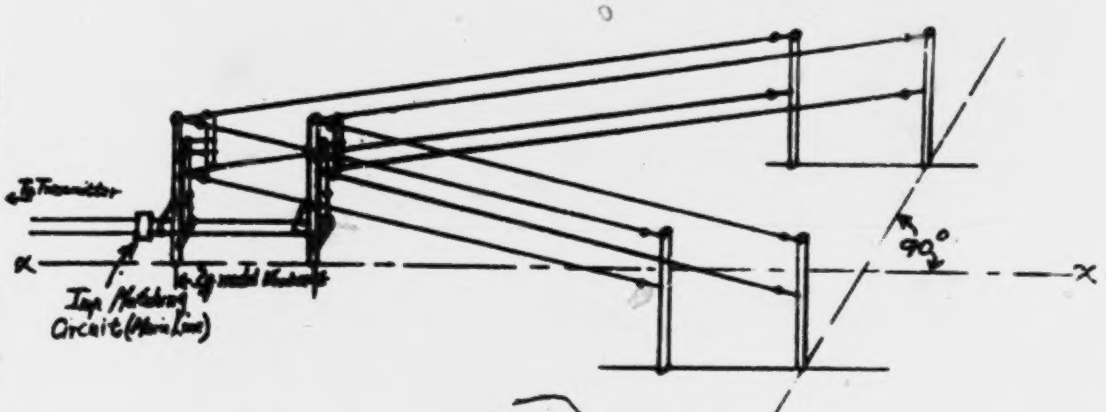

Fig 4.

If greater concentration of radiated energy is desired,
veral units can be operated in parallel as shown in Fig. 5, in
ich case, all units are fed in phase, or an array may be made up
in Fig. 6. In the latter case, the phase difference between the
fferent units is made equal to $2\pi S/\lambda$ where S is the spacing.

It should be understood that this scheme is not limited
two wires in the vertical plane but may be extended to include
y number of wires (preferably an even number) up and down. Fig. 7
ows such a system using 4 wires in the vertical plane spaced
$\lambda/2$ apart.

4 3/5

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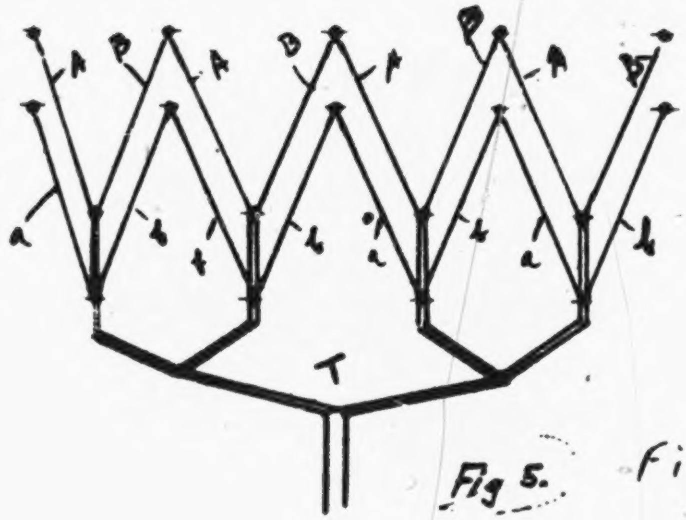
848



~~Fig 5.~~ Fig 8

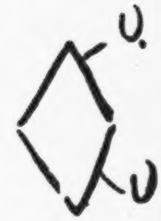
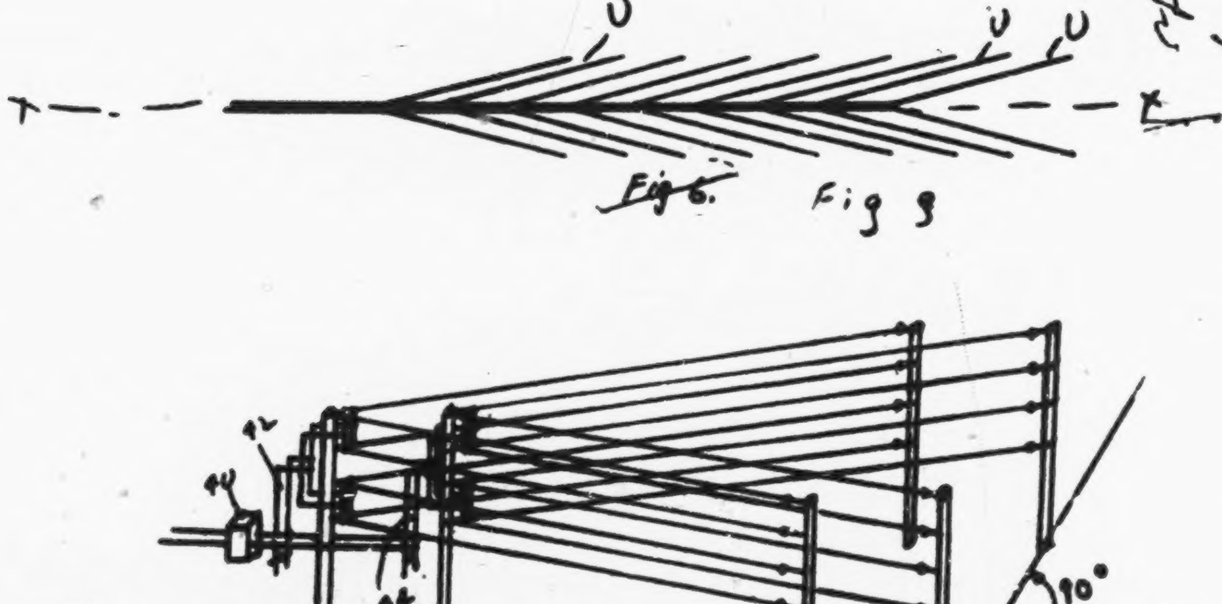
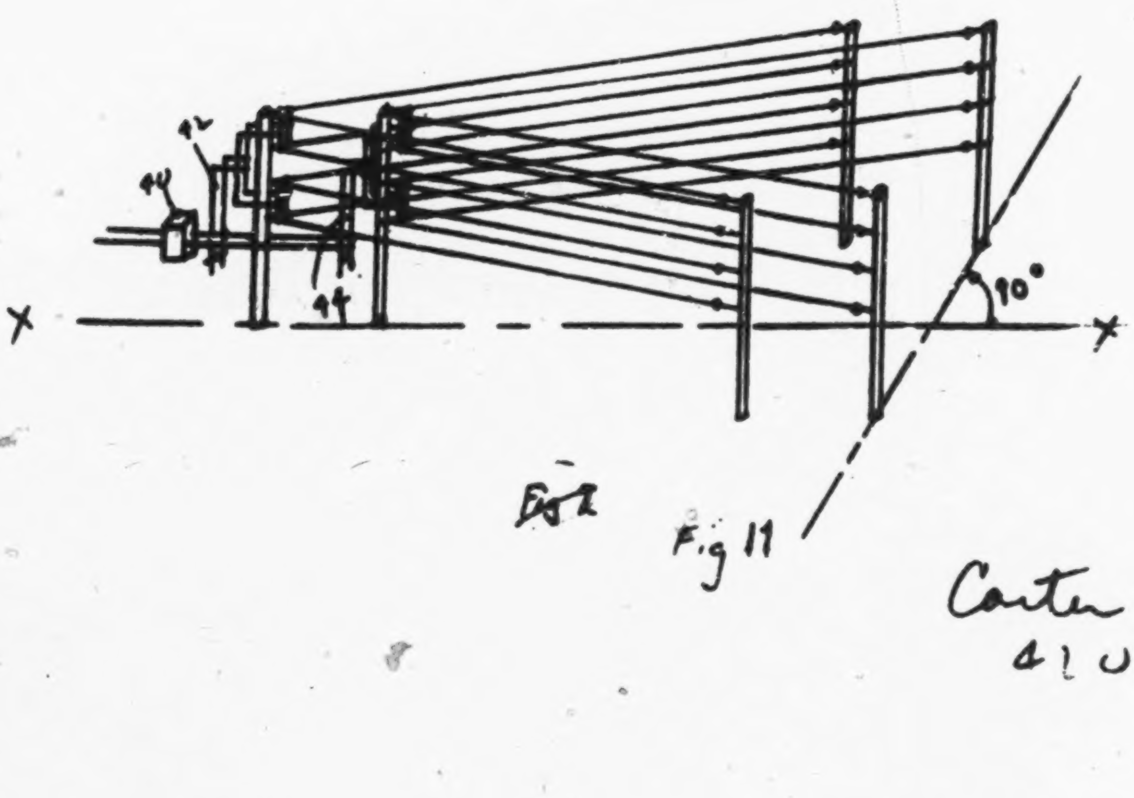


Fig 10

U Fig



~~Fig 6.~~ Fig 9



~~Fig 7~~

Fig 11

Carter
41 US

49/6

NCIPLES OF SYSTEM

It can be shown that the field intensity of the radiated e from a straight wire an odd number of wavelengths long is given the formula E or $H \propto \frac{\cos(n\frac{\pi}{2}\cos\theta)}{\sin\theta}$ and, from a wire an even number wavelengths long by the formula E or $H \propto \frac{\sin(n\frac{\pi}{2}\cos\theta)}{\sin\theta}$, where is the number of halfwaves long and θ the angle to the wire axis. (The symbol $\propto$ indicates "varies as.")

Let Fig. 8 represent two wires A and B forming a "V" and the line mn bisect the angle between the wires. Call the angle ween A or B and mn α. At any point P on the line mn at a great tance from the wires the radiated waves from symetrical elements A and B have traveled equal distances and therefore will arrive time phase at this point if generated by currents which are in the e phase in A and B. However, the electric field vectors E_1 and E_2 will be in opposite directions and no radiation will take place ng this line.

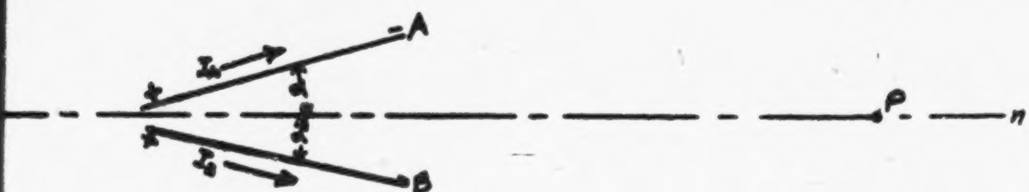


Fig 8.

If currents in phase oppositi.n are flowing in A and B, ch will be the case when fed in the manner shown in either Fig. 9 Fig. 10, the field components will have the same direction at P. , if we make the angle α of the correct value, the maximum radia- n from the pair will take place along the line mn and radiation other directions is to a large extent cancelled. Sheet [redacted] shows correct ues of this angle for various lengths of one side of the "V". When length of each wire is 8 wavelengths and the angle α is 17.5 rees, the power distribution is as has already been shown in Fig. 2.

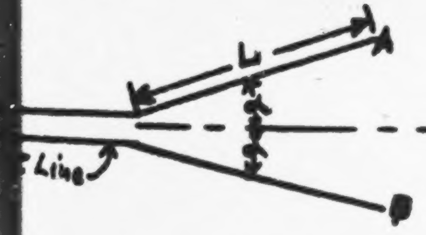


Fig. 9.

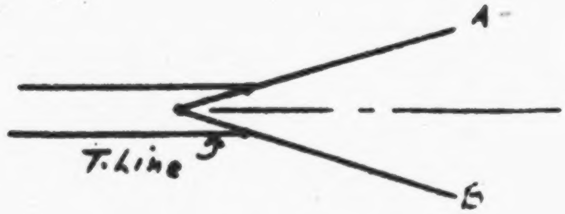


Fig. 10

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If Θ is the direction angle to the line mn the phase angle between the time vector component of the field due to A and that due to B is $\pi + 2\pi\frac{d}{\lambda}\cos\Theta$ where d is the spacing between centers of the wires.

However, $d = 2 \cdot \frac{L}{\lambda} \sin \alpha$. Hence the phase angle ψ_A becomes $\pi + 2\pi\frac{L}{\lambda}\sin\alpha\cos\Theta$

The total field E for any particular angle Θ, is then equal to the vector sum of $E_A + E_B$ and the magnitude of E becomes (See Fig. 11)

$$|E| = \sqrt{E_A^2 + E_B^2 + 2E_AE_B\cos\left(\pi + 2\pi\frac{L}{\lambda}\sin\alpha\cos\Theta\right)}$$

Fig. 11

The intensity if energy flow w is equal to $E \times H = E^2$ and $w = E^2 = E_A^2 + E_B^2 + 2 \cdot E_A \cdot E_B \cdot \cos\left(\pi + 2\pi\frac{L}{\lambda}\sin\alpha\cos\Theta\right)$

Having plotted curves of power distribution for a single wire of length L the field distribution in the plane of the wires can be determined from such curves and the last equation. Fig. 2 was obtained in this manner.

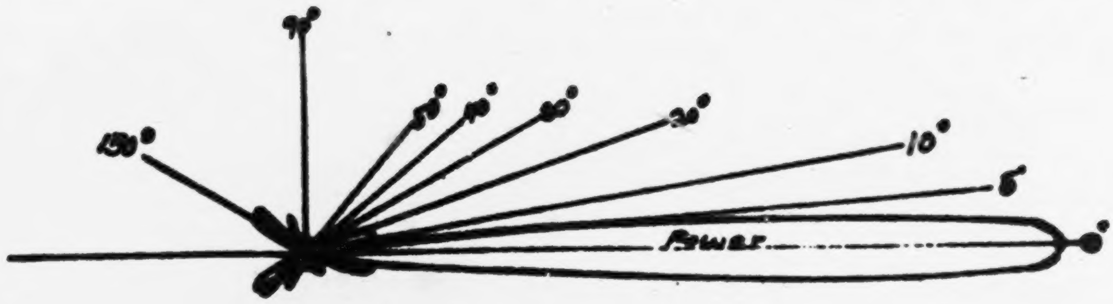
In other planes the directions in space of the components E_A and E_B of the electric field E of the traveling wave are not parallel and in general unequal in magnitude and in different time phase. These facts must be correctly taken into account in determining the resultant field in any direction in space. At any angle in the vertical plane including the line mn the time phase angle is constant and equal to 180 degrees (the currents in the wires being in phase opposition) but the angle between the directions of the field vector components in space varies from 180 degrees in the horizontal direction to 90 degrees in the vertical.

The principles involved in the placing of a duplicate system, or several duplicate systems, all fed in phase and one above the other, to give greater concentration in the vertical plane, are well known and need not be gone into further here. The same applies to the use of two or more systems, one behind the other, fed in successive quarter phase relation, to produce a unidirectional and give further concentration both vertically and horizontally. The principle of using an array of several systems side by side is also well known.

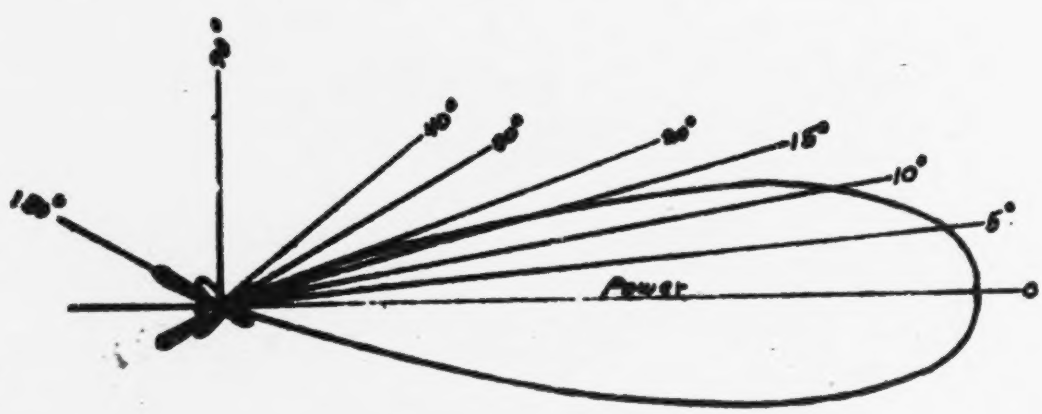
Rocky Point, New York
January 4, 1930

P. S. Carter
P. S. Carter

Harry Tunick
Jan 14/30



Horizontal Plane



Vertical Plane

POWER DISTRIBUTION CURVES
NEW "V" TYPE ANTENNA

Rocky Point, N.Y.
Dec 3 '29
P. S. Carter

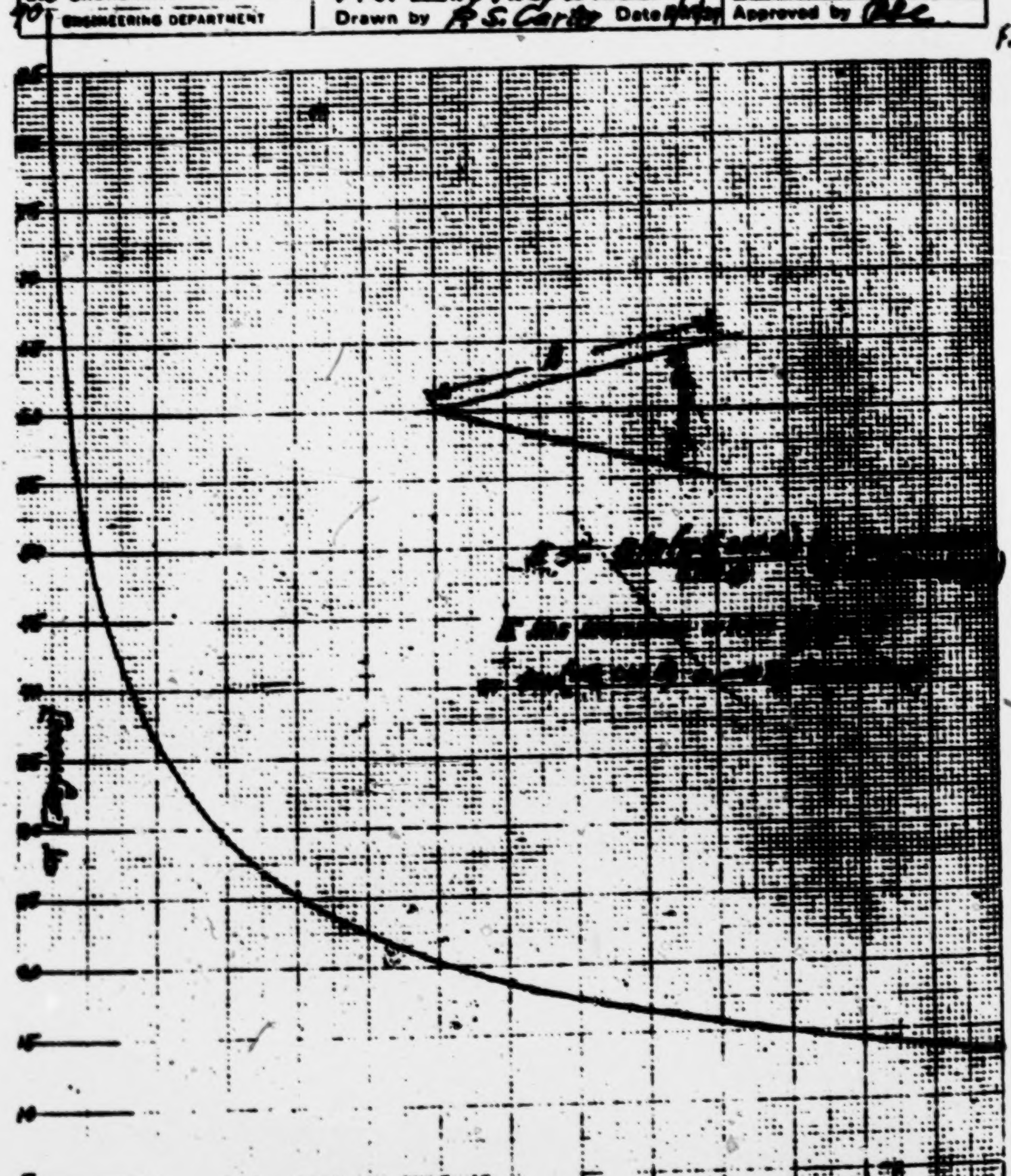
Tunick
1/16/30

43/9

661

852

RADIO CORPORATION OF AMERICA 233 BROADWAY, NEW YORK ENGINEERING DEPARTMENT	Title Correct Angle between Wires for "V" Antenna vrs. Length of Wires Drawn by R. S. Carter Date	No. 8 To Accompany: Approved by



Harry Turnill 1/16/33.

Form 226. 500M. 9-29.

INTERDEPARTMENT CORRESPONDENCE

TO: Patent Department
FROM: Mr. H. Tunick
SUBJECT: Docket 4205

DATE April 1. 1930.
OFFICE
FILE No.

Carter promised to send in further information on this case on March 26, 1930 giving me the relation in simple form between the length of wires used and the angle between them in order to obtain maximum radiation on the line of the bisector.

Harry Tunick

43/4

HT:AU

663
854

Form 100 Com. 1000 6-29

R. C. A. COMMUNICATIONS, INC.

INTERDEPARTMENT CORRESPONDENCE

PATENT DEPARTMENT
RECEIVED
MAY 10 1930

TO: Mr. Harry Tunick, Patent Department
FROM: Mr. P. S. Carter

DATE May 9, 1930
ANSWERED I

SUBJECT: Docket #4205

Dear Mr. Tunick:

Due to the pressure of other work, mostly in connection with tests and adjustments of the antenna system covered by the above docket, I have been delayed in the writing of a more detailed outline of the principles involved in this system.

Attached you will find a revised description of the principles in which I have given a little more detailed explanation of the law by which the correct angle included by the V is determined. I have also corrected the errors which I found I had made in copying from my original notes. You should now have sufficient information to complete the application papers.

A few days ago I forwarded you a copy of the report of tests on this antenna. The results so far have proved even better than I had anticipated and we expect to build a number of commercial models of this system very soon. For this reason I believe it important that patent papers be filed as soon as possible.

It is believed very important to make applications in foreign countries in this case as it seems impossible to keep news from spreading. Yesterday Mr. Winterbottom and others visited our building and were shown this antenna system. Among the party was a man representing the Holland Company. Several years ago we had a case where a visitor from a foreign country observed certain inventions of Mr. Alexanderson in use and within a short time applied for patents in nearly all the countries of Europe. This resulted in our being unable to use our own system in Poland without paying large royalties to this man.

Yours very truly

P. S. Carter

P. S. Carter

PSC/MVN
Cc Mr. C. W. Hansell

H.T. May 10, 1930

#5#

PRINCIPLES OF SYSTEM

The polar diagram of the relative field strength of the radiated wave from a wire several wave lengths long contains as many ears per quadrant as the length of the wire in terms of wave length, For instance, there are four ears per quadrant for a wire four wave lengths long and 4 1/2 ears for a wire 4 1/2 wave lengths long. This is true for any plane including the wire and in a solid diagram these ears become cones. ~~XX~~ Figure A is a polar diagram of relative amplitude for a wire five wave lengths long. The instantaneous direction of the field is reversed for each suceeding ear as indicated by the + and - signs.

The law of variation of field intensity with the direction angle to the wire was deduced by concidering the wire to be equivalent to a very large number of very short doublets and adding up the field components at any point P, having a direction angle Θ to the axis of the wire, while correctly taking into account the relative currents along the wire and the phase differences of the elemental field components due to the differences in time taken to travel to the point P. In this treatment the point P is considered as being at a great distance from the wire as compared to the length of the wire so that all lines become essentially parallel.

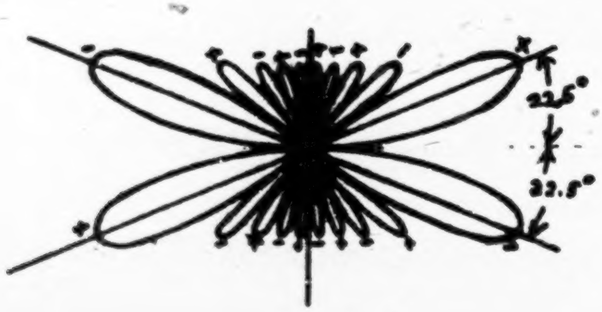


Fig. A.

Such an analysis results in the formulae:

E or H $\propto \dfrac{\cos\left(n\frac{\pi}{2}\cos\theta\right)}{\sin\theta}$ for a wire an odd number of half wave lengths long,

and E or H $\propto \dfrac{\sin\left(n\frac{\pi}{2}\cos\theta\right)}{\sin\theta}$ for a wire an even number of half wave lengths long,

in which "n" is the number of half wave lengths long, Θ, the direction angle to the wire as axis. The symbol "$\propto$" indicates " is proportional to".

Let Fig. 8 represent two wires A and B forming a "V" and let the line mn bisect the angle between the wires. Call the angle between A or B and mn α. At any point P on the line mn, at a great distance from the wires, the radiated waves from symmetrical elements of A and B have traveled equal distances and therefore will arrive in time phase at this point if generated by currents in the same phase in A and B. However, the electric field vectors E_A and E_B will be in opposite directions and no radiation will take place along this line.

Fig. 8

If currents in phase opposition are flowing in A and B, which will be the case when fed in the manner shown in either Fig. 9 or Fig. 10, the field components will have the same direction at P. Now, if we make the value of the angle α that which coincides with the direction of maximum radiation from one wire alone, the maximum radiation from the pair will take place along the line mn and radiation in other directions is to a great extent cancelled. When the length of each wire is 8 wave lengths and the angle α is 17.5 degrees the power distribution in the plane of the wires is as has already been shown in Fig. 2.

Fig. 9 Fig. 10

The correct value of the angle α is value of θ for which

$\frac{\cos\left(n\frac{\pi}{2}\cos\theta\right)}{\sin\theta}$ is a maximum when the wires are an odd number of

half wave lengths long and the value of θ for which $\frac{\sin\left(n\frac{\pi}{2}\cos\theta\right)}{\sin\theta}$

is a maximum when an even number of half wave lengths long. The following two equations give this angle exactly for these two cases:

α = the smallest value obtained from $\tan\left(n\frac{\pi}{2}\cos\alpha\right) = n\frac{\pi}{2}\tan\alpha\sin\alpha$

for wires an odd number of half wave lengths long.

α = the smallest value obtained from $\tan\left(n\frac{\pi}{2}\cos\alpha\right) = -n\frac{\pi}{2}\tan\alpha\sin\alpha$

for wires an even number of half wave lengths long.

The curve of Sheet 8 gives the values of this angle for lengths up to 14 wave lengths. For practical purposes the

empirical formula $\alpha = 50.9(l/\lambda)^{-0.513}$ Degrees (where l = length and λ = wave length, both in same units of measure) is sufficiently accurate.

The power distribution in the plane of the wires for the V element can be obtained as follows: If ϕ is the direction angle to the center line of the pair the phase angle between the time vector component of the field due to A and that due to B is

$\pi + \frac{2\pi d}{\lambda}\sin\phi$ where d is the spacing between centers of the wires.

However, d = $l \sin\alpha$ sin ϕ. Hence the phase angle ψ becomes

$\pi + \frac{2\pi l}{\lambda}\sin\alpha\sin\phi$. The magnitude of the total electric field E for any particular angle ϕ is then equal to the vector sum of

of E_A and E_B and the magnitude of E becomes(See Fig. 11)

$$|E| = \sqrt{E_A^2 + E_B^2 + 2 E_A \cdot E_B \cos\left(\pi + 2\pi \frac{L}{\lambda} \sin\alpha \sin\phi\right)}$$

Fig. 11

The intensity of energy flow (power) w is equal to $E \times H = E^2$

and $w = E^2 = E_A^2 + E_B^2 + 2 \cdot E_A \cdot E_B \cos\left(\pi + 2\pi \sin\alpha \sin\phi\right)$

Having determined the curves of field distribution for a single wire of length L substitution of values obtained from these curves in the above equation (with due regard to signs) gives the desired values of intensity of radiation in various directions from the element.

In other planes the directions in space of the components E_A and E_B of the electric field E of the traveling are not the same and, in general, of unequal magnitude and in different time phase. These facts must be correctly taken into account in determining the resultant field in any particular direction in space. At any angle in the vertical plane including the line mn the time phase angle is constant and equal to 180 degrees (the currents in the wires being in phase opposition) but the angle between the field vector components in space varies from 180 degrees in the horizontal direction to 2α in the vertical.

The principles involved in the placing of a duplicate system, or several duplicate systems, all fed in phase and one above the other, to give greater concentration in the vertical plane are well known and need not be gone into further here. The same applies to the use of two or more systems fed in successive quarter phase relation, to produce a unidirectional system and give further concentration both horizontally and vertiwally. The principle of using an array of several systems side by dide is also well known.

The are numerous other combinations of the above described element which I have not shown such as two V combinations placed ~~xxxx~~ so as to form a diamond, two V's crossing at the center of their sides and further combinations of these combinations.

Rocky Point, N. Y.
May 8, 1930.
P. S. Carter
P. S. Carter

H.T. May 10, 1930

43/15

858
667

Form 836. 90M. 9-29.

INTERDEPARTMENT CORRESPONDENCE

TO: Mr. P. S. Carter
FROM: Mr. Harry Tunick

DATE May 14, 1930.

.......................OFFICE

SUBJECT:

FILE No.

I am sending you herewith a rough draft of United States patent application papers covering your invention described in our docket 4206. Please feel free to make thereon any additions, corrections or suggestions which will tend to more fully disclose the invention.

After inspecting the rough draft please return it to me so that I may have the final papers drawn up for you to execute.

Harry Tunick

HT:AU
ENCS.

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DOCKET 4265

Return to

TO ALL WHOM IT MAY CONCERN:

BE IT KNOWN THAT I, PHILIP STAATS CARTER, a citizen of the United States, and a resident of Port Jefferson, Long Island, New York, have invented certain new and useful improvements in

ANTENNAE

of which the following is a specification ~~accompanied by drawings~~:

This invention relates to antennae and especially to directional antennae or antennae systems.

If a wire ~~relatively~~ long, relative to the working wave length; namely, a plurality of half wave lengths long, is excited in a fashion such that standing waves are produced thereon, ~~principle~~ radiation will occur principally in the ~~form~~ direction of symmetrical cones having their apices at the center of the wire. In cross section, the radiation characteristic would appear as symmetrical hollow cones about the wire. ¶ An object of the present invention is to utilize this phenomena for the directive radiation of electromagnetic energy. To do so, a pair of wires or linear conductors ~~relatively~~ long relative to the working wave length are disposed at an angle such that principal radiation takes place along the bisector of the angle. This angle, in general corresponds to the angle of the principal cone of radiation about one of the conductors.

Still a further object of the present invention is to disclose the proper angle for ~~wires~~ conductors or radiators either an even number of half wave

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lengths long or an odd number of half wave lengths long, and in general to disclose the angle for best directional propagation for wires of any finite length.

A pair of conductors disposed in the manner described will radiate equally well in two directions, namely, towards the diverging end of the wires and towards ~~away from~~ the converging end of the wires. That is to say, the antenna system so far described is bidirectional.

A further object of the present invention is to provide ~~an~~ arrangement ~~whereby the system becomes~~ unidirectional. This is accomplished by placing a similar parallel pair of wires an odd number of quarter wave lengths away from the wires forming the antenna proper in a ~~the~~ direction taken along the bisector or the angle formed by the wires. The second pair of wires may be left unenergized or floating, or they ~~may~~ be energized in proper phase such that for one direction radiation cancelation occurs, whereas in the other direction there is strengthening of ~~the~~ propagated ~~propagation of~~ electromagnetic waves.

~~Ordinarily, the antenna so far described will have the pairs of wires in a horizontal plane whereby the beam of energy radiated occupies a small horizontal angle.~~ To concentrate the beam in a transverse plane, at right angles to the plane of the pairs of wires, usually the vertical plane ~~direction, namely, vertically~~, since the pairs are ordinarily disposed in horizontal planes, is a further object of the present invention, and, this is accomplished by placing similar pairs of wires in planes parallel to the planes of the first mentioned pairs of wires the planes being spaced apart preferably at least a ~~an odd~~ ~~number of~~ half wave length.

To additionally concentrate the beam of energy radiated, systems of the nature outlined heretofore may be placed in broadside whereby there

is added concentration of the radiated beam of energy in a horizontal plane, and, by placing more systems or stories of systems above one another, there will be added concentration of a beam in a vertical plane ~~direction.~~ The invention is further described in connection with the accompanying drawing, in which

Figure 1a illustrates generally the principal conal radiational characteristic of a long conductor upon which standing waves are produced,

Figure 1b illustrates in cross section, the radiation characteristic of a wire five wave lengths long,

Figures 2a, 2b and 2c indicate various forms of the fundamental unit of the present invention wherein long linear conductors having standing waves thereon are disposed at an angle such that principal radiation occurs along the direction of the bisector of the angle,

Figure 3 indicates the bidirectional characteristic of one of the units shown in figure 2.

Figure 4 illustrates an antenna system for concentrating ~~[illegible]~~ the directional beam radiated from one of the units shown in figure 2,

Figure 5 illustrates the arrangement of a plurality of units such as shown in figure 2 for obtaining unidirectional propagation ~~[illegible]ical plane~~,

Figures 6 and 7 illustrate respectively, the power distribution in the horizontal and vertical planes from an antenna system such as shown in figure 5,

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Figure 8 illustrates a broadside arrangement of unidirectional units for further ~~concentrating~~ increasing the directivity of ~~the~~ beam ~~in a horizontal plane~~ of propagated electromagnetic waves,

Figure 9 indicates, in plan view, an end-on or in line arrangement of units for ~~concentrating the~~ increasing the directivity of a beam ~~in a horizontal plane~~ of waves,

Figures 10 and 10a indicate diamond shaped arrangements of ~~conductor paths~~ units for obtaining unidirectional propagation,

Figure 11 illustrates a preferred form of the invention for concentrating a unidirectional beam of energy horizontally and vertically, when the length of wires is of the order of 6 to 12 wavelengths and

Figure 12 is a graph showing the proper relationship between the length of a single conductor of a pair of conductors and the angle to be given ~~at~~ it relative to a desired direction of propagation according to the present invention.

In general, as shown in figure 1a, about a wire 2 ~~long~~ long, relative to the working wave length, there are two principle hollow cones 4, 6 of radiation. The cones are symmetrical about the wire 2 and the axis of the cones coincides with that of the radiator 2. For a given wire, at a given wave length, the angle α between the axis Y-Y, of each lobe or ear of the cone which appears as such in cross section, and the wire 2 ~~remains substantially~~ is constant.

More specifically, a cross section of the solid polar diagram ~~for~~ of a wire ~~having~~ a number of wave lengths long having standing waves thereon, contains as many ears per quadrant as there are wave lengths in the wire. Thus, as shown in figure 1b, for a wire five wave lengths

long, there are five ears in each quadrant, the principal lobes of radiation occurring along the axis Y-Y. As indicated, the instantaneous direction of the field represented by each ear is reversed.

Now, if it is desired to radiate energy principally in the direction of axis XyX of figure 2, the conductors, shown in figure 1, should be turned an angle α relative to the direction XyX; and, in order to increase still further the directional characteristic along the axis XyX, according to the present invention, two wires ~~should be~~ are used which make an angle α with the axis XyX on opposite sides of the axis in such a fashion that the axis and the pair of wires lie in a single plane. In other directions than along the axis XyX, radiation cancelation will occur ~~namely~~ mainly, as a result of which, a pair of wires disposed at the angle α with respect to the XyX axis will have a radiation characteristic in the plane of the pair of wires such as shown in figure 3.

By considering a long wire the equivalent of a very large number of ~~short half wave~~ very short (Hertz) oscillators, and by adding up the field components at any point P having a direction angle θ relative to the axis of the wire where the point P is ~~considered as being~~ a great distance from the wire as compared to the length of the wire such that all lines from point P to any point on the wire are essentially parallel, it can be shown that the field strength H is given by the following proportionality for a conductor an odd number of half wave lengths long:

$$H \propto \frac{\cos\left(x \frac{\pi}{2} \cos\theta\right)}{\sin\theta}$$

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The legend "n" indicates the number of half wave lengths contained in the wire.

For a wire an even number of half wave lengths long, in similar fashion, [redacted] the field strength H, is given by the following proportionality:

$$H \propto \frac{\sin\left(n\frac{\pi}{2}\cos\theta\right)}{\sin\theta}$$

Where n as above, indicates the number of half wave lengths on the wire.

The value for which the angle θ in either of the above equations makes the expression a maximum value gives, of course, the value for the angle α ~~with~~ the wire should be disposed at relative to the direction ~~X-X~~ of desired wave propagation. ~~The manner of~~ The obtaining the critical value of θ for either of the above equations may, obviously, be ~~simply~~ readily determined, ~~The~~ Its value ~~of the angle~~ for wires up to fourteen wave lengths long is given graphically in figure 12. For practical purposes the ~~imperial~~ empirical formula

$$\alpha = 50.9\left(\frac{l}{\lambda}\right)^{-0.513} \text{ degrees}$$

where l equals the length of the wire and λ the wave length, both in the same units of measurement, is sufficiently accurate. Where a pair of wires are used in accordance with the present invention, they should be ~~spaced~~ apart at an angle equal to twice the angle α as determined in any of the ~~manners~~ ways described above.

4/3/22

In order to obtain a bidirectional unit having a characteristic as shown in figure 3, as already indicated, any of the arrangements n in figure 2 may be utilized. The fundamental unit is shown in re 2a where a transmission line 10 supplies high frequency energy pair of wires A,B forming the angle 2 α with each other, ~~and~~ The the angle made by one of the conductors e α with the axis X-X along which it is desired that the radiators propagate energy. The conductors A,B, are joined together at their which falls in ~~[illegible]~~ the axis X-X as shown, ~~and~~ The wires are fed intermediate r ends in a fashion similar to that in which a half wave length illator is fed intermediate ~~their~~ its ends, ~~[illegible] mission line 10~~ desired, of course, as shown in figure 2b the transmission line 10 terminate ~~directly [illegible]~~ the extremities of linear radiators A,B, rather connect them together.

The arrangement shown in figure 2c is, however, preferred, for allows of tuning of the antenna unit comprising the pair of wires A,B. transmission line 10 feeds energy to a U-shaped loop 12 ~~one-half~~ ~~length long~~, the legs of which are short circuited by an adjustable rt circuiting strap 14 ~~which, of course,~~ represents a voltage nodal nt. The ends 16 of the loop 12 ~~are during always at maximum potentials~~ supply energy in phase opposition to the conductors A,B. Adjustment impedance such that there is no reflection along transmission line 10 accomplished along the legs of the loop by suitable adjustable tapping nts 18.

It ~~may~~ should be mentioned here that energy to the radiators A,B uld always be fed thereto out of phase for otherwise at a distant nt P along the axis X-X there would be radiation cancelation, and ~~it~~ is

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Moreover, it should be clearly understood that the wires of each unit can be of any length whatsoever provided they are placed at the correct angle [redacted] for their length. For best tuning, the total over-all length of both of the wires and the "U" loop terminating them should be effectively an integral number of half wave lengths, but, [redacted] the portion forming the [redacted] radiation element can be of any length, [redacted]. The law giving [redacted] the correct angle for lengths between odd and even number of half wave lengths, is not given due to its complexity, but, the empirical formula and the curve of figure 12 will be found [redacted] accurate for all practical purposes, where the length of wire dealt with does not correspond to a whole number of half wave lengths.

43/24

INSERT 2 - DOCKET 4205

The vertical spacing of the units one above the other need not be made an integral number of half wave lengths. ~~The spacing of a half wave length prevents vertical radiation.~~ In addition it should be noted that for wires several wave lengths long, vertical radiation is either zero or practically very small. Specifically, it is zero for wires whose lengths are equal to an even number of half wave lengths, and small for wires an odd number of half wave lengths long. For wires whose length approaches the order of magnitude from 6 to 10 wave lengths, a spacing greater than one half wave length is preferred. ¶ In practice, where the height of the antenna is limited by economical considerations and wherein it is desired to make ground absorption as low as possible, a good compromise is a half wave length spacing. For transmission of energy having a wave length of 17 or 18 meters, a good practical antenna may be had wherein the lower wires are about three-quarters of a wave length above ground, and the spacing between wires is one-half wave length. Eighty ~~[illegible]~~ feet poles or masts may be used to support the wires ~~[illegible] antenna of this character.~~

43/25

to be understood that the unit so far described is not only useful for radiation purposes but may be utilized equally as well for reception. That is, the antenna system accordin to the present invention is equally well suited for any type of radiant action whether it be collection of radiation energy or the transmission ~~radiation~~ thereof.

In order to prevent undesired high angle ~~vertical~~ radiation, and in order to concentrate the desired beam in elevation, the scheme shown in figure 4 may be utilized. Here, pairs of wires A,B and A',B' are placed in parallel horizontal planes and supported by masts 20 and suitably insulated therefrom by suitable insulators 22. Both pairs of wires [illegible] are fed cophasally from a transmission line 24 through conductors 26, the wires of each pair or unit being ~~[illegible]~~, fed in opposite phase. In order to increase the directional concentration of radiated energy, ~~[illegible]~~ the pair A,B and the pair of wires A' and B' are placed apart in horizontal planes by any convenient spacing ~~[illegible] number of half wave lengths~~ and preferably at least one-half wave length apart. The lines [illegible] should be at least one half wave length or greater [illegible] Bidirectional propagation ensues ~~by the double structure~~ along the axis X-X but in a much more concentrated form relative to the use of a single unit. In order to obtain a unidirectional radiation characteristic, pairs of units such as shown in figure 3 may be spaced parallel and apart a distance along the axis X-X or along ~~through~~ the bisector of the angle formed by each pair of wires in each unit a distance equal to an odd number of quarter wave lengths. Such a system combined with means for concentrating the beam in a direction traversing the plane of the wires of each unit is shown in figure 5. That is, figure 5 illustrates a

system such as shown in figure 4 duplicated in a direction along the Y,X axis whereby, in a horizontal plane, a directional characteristic is obtained such as that shown in figure 6 ~~and~~, in a vertical plane ~~having~~ a power distribution characteristic and as shown in figure 7.

~~Referring to figure 5~~, The unit, in system of figure 5, comprising the pair of wires A,B ~~is~~ paralleled by similar pairs a, b spaced apart along the direction Y,X an odd number of quarter wave lengths and, as shown ~~three~~ nine-quarters of a wave length behind the apex 28 of wires A, B, ~~by~~ is excited ~~exciting~~ so that the wires a,b, [illegible] have standing current waves thereon ~~are~~ 90 degrees ahead in phase of the standing current waves on wires A,B. Consequently, energy will be propagated principally along the axis Y,X towards the diverging ends of the radiators. In order to concentrate the beam of energy so radiated, similar pairs of radiators are placed below the pairs A,B and a, b in planes suitably spaced from the first mentioned pairs of radiators to obtain the desired vertical or directional concentration. ~~in a vertical direction.~~ The lower pairs of radiators are excited cophasally with the upper pairs ~~by~~ through conductors 26, 26' fed by transmission line 24. In order to tune the various units U-shaped loops 30, 30' are provided, short circuited by straps 32, 32'.

Of course, by exciting wires a,b 90 degrees lagging relative to radiators A,B, unidirectional propagation may be obtained in an opposite direction, or, towards the converging ends or apices of the units.

If greater concentration of the radiated energy is desired several systems such as shown in figure ~~6~~ 5, for example, comprising an

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effective radiating unit AB and an effective reflecting unit ab may be placed in broadside and excited cophasally. Thus, in figure 8 each of the radiating units A, B shown in plan is provided with a reflecting unit a, b. Through branched transmission lines as shown diagrammatically at T each system is fed cophasally as a result of which an extremely concentrated beam of energy ~~in~~ the ~~[illegible]~~ plane of the units is transmitted in a direction from the reflecting units towards the radiating units or the reverse, depending upon the relative phase of the standing waves thereon.

The units may be arranged in end-on fashion or coaxially as shown in figure 9 ~~for~~ wherein each of the units U is spaced apart in the direction of desired propagation. By making the phase difference ~~[illegible]~~ between each of ~~each of~~ the units ~~[illegible]~~ equal to $2\pi\frac{S}{\lambda}$ where S is a spacing of each unit measured ~~of~~ along the axis, concentrated unidirectional propagation may be obtained in either direction along the X-X axis depending upon whether or not the standing waves on the succeeding units lag or lead each other by the phase difference~~s~~ given according to the foregoing expression.

Other combinations will readily suggest themselves to those skilled in the art, for example, the units U may be placed diamond shaped fashion such as shown in figure 10, or, they may be superimposed as shown in figure 10a, the wires of each unit traversing each other.

In ~~[illegible]~~ order to obtain greater concentration of the radiated beam of energy in a direction traversing the plane of each unit, the systems may be extended in the fashion shown in figure 11.

INSERT 3 - DOCKET 4205

The spacing of the antenna and reflector of the system shown in figure 11 where the wires are 6 to 12 wave lengths long is made preferably nine-quarters of a wave length. For wires longer than ten wave lengths, the preferred form should have a greater spacing between the antenna and reflector such as two and three-quarters or three and one-quarter wave lengths. For wires on the order of three or four wave lengths long, the reflector spacing from the antenna should be one and one-quarter wave lengths or less. In general, for maximum concentration, as the length of wires in terms of wave lengths increase, the reflector and antenna spacing should be increased.

INSERT 4

Use of the loop allows of completion of the tuning of the antenna wires by making the total effective tuning length of each wire of the "V" or radiating unit equal to an odd number of quarter wave lengths. The effective radiating length is the length of wire included in the "V" only, since the loop is non-radiating and can be made of any length.

When tuning of the "V" is properly accomplished by the U-loop, the systems presents a pure resistive load to the transmission line. By tapping the line to the legs of the U at a suitable distance from the short circuiting strip, the effective

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resistance of the antenna system can be made equal to the surge impedance of the line, which is a necessary condition for maximum transmission efficiency.

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Here, the system of figure 5 has been duplicated in a vertical direction, giving increased concentration of the beam in elevation. Energy is fed to the system through an impedance matching device 40 and thence cophasally to the reflecting units through a suitable connection 42. Energy is similarly fed to the radiating units through a suitable connection 44. By suitably tuning and by suitably spacing of the radiating pairs of wires and reflecting pairs of wires, unidirectional propagation may be obtained in ~~their~~ either direction along the bisector of the angle formed by the wires of each pair.

In each of the systems, of course, for reception, the transmission line would simply be coupled to a suitable receiver, the antenna being directed upon a transmitting station. The wires, though preferably placed in horizontal planes, may be placed at any desired angle without departing from the scope of this invention, and, during transmission it may often be found desirable to have the plane of the wires tilted away from the wall and towards the direction ~~on~~ in which the beam of energy is to be propagated.

Having thus described my invention, what I claim is:

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DOCKET 4205

1. A directional antenna comprising a pair of angularly disposed linear conductors, each substantially a plurality of half wave lengths long and having standing waves thereon whereby radiant action of the antenna is predominantly along the direction of the bisector of the angle formed by the conductors.

2. A directional transmitting antenna comprising a pair of angularly disposed linear conductors, each substantially a plurality of half wave lengths long and open-ended, and, means for exciting the radiators in phase opposition whereby standing waves of opposite instantaneous polarity are formed on the radiators.

3. A directional antenna comprising a pair of angularly disposed linear conductors disposed in a horizontal plane, each substantially a plurality of half wave lengths long and having standing waves thereon whereby radiant action of the antenna is predominantly along the direction of the bisector of the angle formed by the conductors.

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4. A directional transmitting antenna comprising a pair of angularly disposed linear conductors, each substantially a plurality of half wave lengths long ~~and~~ open-ended and disposed in a horizontal plane, and, means for exciting the radiators in phase opposition whereby standing waves of opposite instantaneous polarity are formed on the radiators.

5. A directional antenna comprising a pair of angularly disposed linear conductors, each substantially a plurality of half wave lengths long and having standing waves thereon whereby radiant action of the antenna is predominantly along the direction of the bisector of the angle formed by the conductors, and another pair of conductors parallel and similar to said first mentioned pair of conductors and spaced therefrom an odd number of quarter wave lengths measured in a direction ~~of~~ along the bisector of the angle of the conductors.

6. A directional transmitting antenna comprising a pair of angularly disposed linear conductors, each substantially a plurality of half wave lengths long and open-ended; ~~and~~, means for exciting the radiators in phase opposition whereby standing waves of opposite instantaneous polarity are formed on the radiators; and, another pair of conductors similar and parallel to said first mentioned pair of conductors and spaced therefrom in a direction ~~measured~~ along the bisector of the angle of the conductors ~~by~~ an odd number of quarter wave lengths.

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7. A directional antenna comprising a pair of angularly disposed linear conductors disposed in a horizontal plane, each substantially a plurality of half wave lengths long and having standing waves thereon whereby radiant action of the antenna is predominantly along the direction of the bisector of the angle formed by the conductors, and another pair of conductors similar and parallel to said first mentioned pair of conductors and spaced therefrom in a direction [redacted] along the bisector of the angle of the conductors by an odd number of quarter wave lengths.

8. A directional transmitting antenna comprising a pair of angularly disposed linear conductors, each substantially a plurality of half wave lengths long and open-ended and disposed in a horizontal plane; [redacted], means for exciting the radiators in phase opposition whereby standing waves of opposite instantaneous polarity are formed on the radiators, and another pair of conductors similar and parallel to said first mentioned pair of conductors and spaced therefrom in a direction [redacted] along the bisector of the angle of the conductors by an odd number of quarter wave lengths.

9. A directional antenna comprising a pair of angularly disposed linear conductors, each substantially a plurality of half wave lengths long and having standing waves thereon whereby radiant action of the antenna is predominantly along the direction of the bisector of the angle formed by the conductors, and another pair of conductors similar to said first mentioned pair of conductors spaced in a direction transversing the planes of said pair. apart from said first mentioned pair ~~an odd number of half wave lengths the spacing being taken in a direction perpendicular to the planes of the pairs of conductors.~~

10. A directional antenna comprising a pair of angularly disposed linear conductors, each substantially a plurality of half wave lengths long and having standing waves thereon whereby radiant action of the antenna is predominantly along the direction of the bisector of the angle formed by the conductors; and another pair of conductors similar to said first mentioned pair of conductors spaced apart from said first mentioned pair, an ~~odd~~ number of half wave lengths, ~~the spacing being taken~~ in a direction perpendicular to the planes of the pairs of conductors.

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11. An antenna comprising parallel pairs of angularly disposed conductors spaced apart along the direction of the bisector of the angle formed by the conductors an odd number of quarter wave lengths, and, similar pairs of conductors in planes parallel to + spaced from the planes of the first mentioned pairs of conductors, [redacted].

12. A transmitting antenna system comprising parallel pairs of angularly disposed conductors arranged in a horizontal plane having their apices spaced apart an odd number of quarter wave lengths, and similar pairs of conductors disposed in a parallel horizontal plane a distance away from said first mentioned plane equal to one or more [redacted] half wave lengths.

13. An antenna comprising a pair of linear conductors, each substantially an odd number of half wave lengths long and angularly disposed at an angle equal to twice the angle for which the expression $\frac{\cos(n\frac{\pi}{2}\cos\theta)}{\sin\theta}$ is a maximum.

14. An antenna comprising a pair of linear conductors each substantially an even number of half wave lengths long and disposed at an angle substantially equal to twice the angle for which the expression $\frac{\sin(n\frac{\pi}{2}\cos\theta)}{\sin\theta}$ is a maximum. 43/36

15. An antenna comprising a pair of linear conductors, each substantially an odd number of half wave lengths long and angularly disposed at an angle equal to twice the angle θ for which the expression $\frac{\cos\left(n\frac{\pi}{2}\cos\theta\right)}{\sin\theta}$ is a maximum, and a similar pair of conductors spaced from said first pair by an odd number of quarter wave lengths in a direction along the bisector of the angle of the conductors.

16. An antenna comprising a pair of linear conductors each substantially an even number of half wave lengths long and disposed at an angle substantially equal to twice the angle for which the expression $\frac{\sin\left(n\frac{\pi}{2}\cos\theta\right)}{\sin\theta}$ is a maximum, and a similar pair of conductors spaced from said first pair by an odd number of quarter wave lengths in a direction along the bisector of the angle of the conductors.

17. An antenna comprising a pair of linear conductors, each substantially an odd number of half wave lengths long and angularly disposed at an angle equal to twice the angle for which the expression $\frac{\cos\left(n\frac{\pi}{2}\cos\theta\right)}{\sin\theta}$ is a maximum, and a similar parallel pair of conductors ~~a distance~~ away from the first mentioned pair ~~measured~~ in a direction perpendicular to the planes of the pairs, ~~of [illegible]~~. 4/3/37

18. An antenna comprising a pair of linear conductors each substantially an <u>even</u> number of half wave lengths long and disposed at an angle substantially equal to twice the angle for which the expression $\frac{\sin\left(n\frac{\pi}{2}\cos\theta\right)}{\sin\theta}$ is a maximum, and a similar pair of conductors a ~~distance~~ away from the first mentioned pair ~~measured~~ in a direction perpendicular to the planes of the pairs, ~~of an odd number of half wave lengths.~~

19. An antenna comprising a pair of relatively long conductors disposed at an angle substantially equal to twice $50.9\left(\frac{l}{\lambda}\right)^{-0.513}$ degrees.

20. An antenna comprising a pair of relatively long conductors disposed at an angle substantially equal to twice $50.9\left(\frac{l}{\lambda}\right)^{-0.513}$ degrees; and, a similar parallel pair of conductors spaced an odd number of quarter wave lengths away from said first mentioned pair ~~measured~~ along the bisector of the angle of the conductors.

21. An antenna comprising pairs of long conductors, the conductors of each pair disposed at an angle substantially equal to twice $50.9\left(\frac{l}{\lambda}\right)^{-0.0}$ degrees, and the pairs being placed in planes substantially an~~d~~ odd number of half wave lengths apart.

22. An antenna comprising pairs of relatively long conductors the conductors of each pair disposed at an angle substantially equal to twice $50.9\left(\frac{l}{\lambda}\right)^{-0.513}$ degrees the apices of each pair being separated by an odd number of quarter wave lengths; and, similar pairs of conductors in a substantially parallel plane~~s~~, ~~substantially and odd number of half wave lengths apart away from the plane of the first mentioned pairs of conductors~~.

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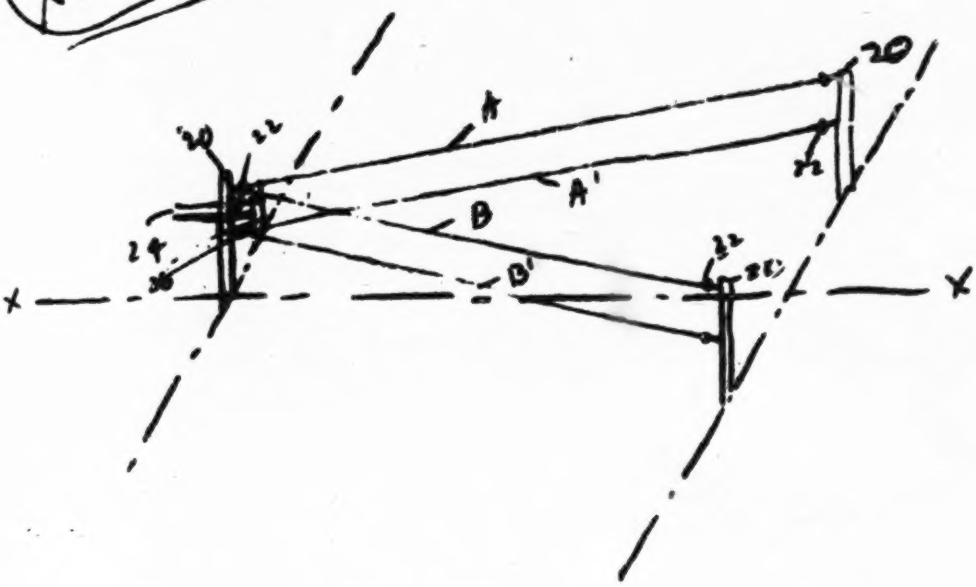
See Fig 2 of Pg 2



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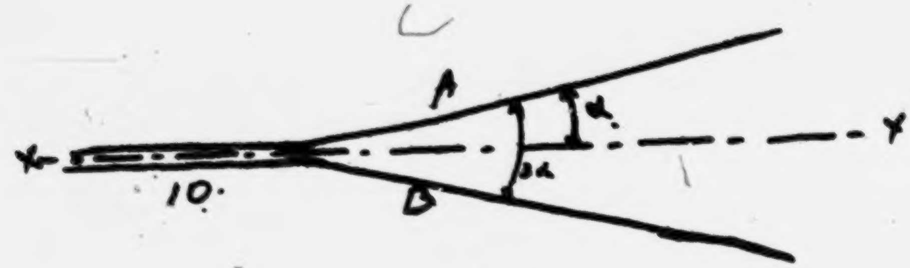


Fig 2b

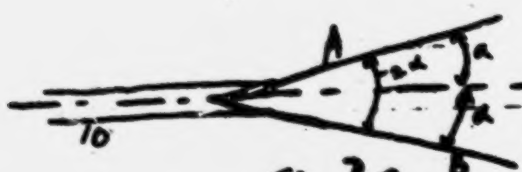


Fig 2a

Fig 2c

Fig 1a

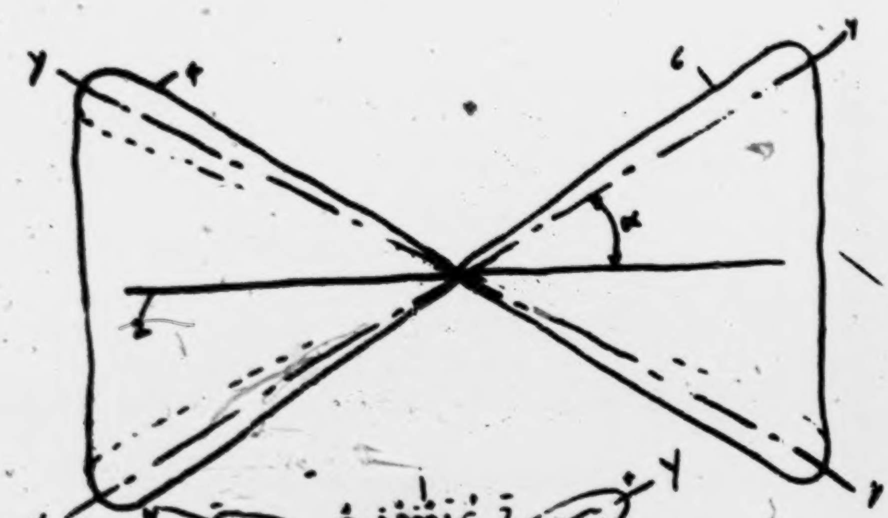
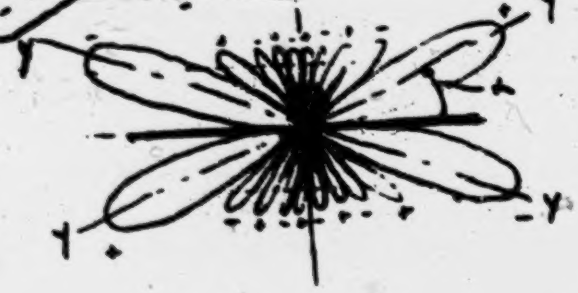


Fig 1b



P.S. Carter
4205

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Form RB Com. 304 6-29

R. C. A. COMMUNICATIONS, INC.

INTERDEPARTMENT CORRESPONDENCE

PATENT DEPARTMENT
RECEIVED
MAY .. 1930

Rocky Point, New York

TO: Mr. Harry Tunick, Patent Department
FROM: Mr. P. S. Carter

DATE May 29, 1930
FILE No. I

SUBJECT: Docket #4205

Dear Mr. Tunick:

I am returning the rough draft of the patent application covering Docket #4205 after having made a number of notations in red pencil. These red pencil notations principally cover statements which appear to me to be either misleading or incorrect.

It appears to me that there are some statements in the specification which need a little clarifying. On page one one might gain the impression that it is essential for the proper working of this system that the length of the wires must be an integral number of half wavelengths. These wires can be any length whatever provided the angle is made correct to correspond. For the best tuning the total overall length of both the wires and the "U" loop should be effectively an integral number of half wavelengths but the portion forming the radiation element can be of any length whatever. The law for determining the angle for lengths lying in between odd and even numbers of half waves was not given due to its complexity but the curves and the imperical formula gives the correct values.

1) On page two a statement was made that the spacing of units one above the other should be an integral number of half wavelengths. Such spacing is not essential. The spacing of a half wavelength would prevent radiation vertically upward but for wires several wavelengths long vertical radiation is either zero or very small to start with. (Zero for lengths equal to an even number of half waves and small for an odd number of half waves). For lengths in the order of 6 to 10 wavelengths a spacing greater than one half wavelength would be better. However, in practice, where height is limited by economy and we wish to make the absorption due to ground as low as possible, the half wavelength spacing is the best compromise. This results in the lower wire being about 3/4 of a wavelength above ground and the spacing between wires 1/2 wavelength when 80 foot poles are used for an antenna for transmission at 17 to 18 meters. In this case the main field is quite weak at the ground and ground losses are reduced to a low value.

2) On page four the statement is made that Figure 11 illustrates the preferred form of the invention. This is true for wires on the order of 6 to 12 wavelengths long. For wires longer than 10 wavelengths, the preferred form would have a greater spacing between the antenna and reflector, such as 2-3/4 or 3-1/4 wavelengths. For wires on the order of three or four wavelengths long the reflector spacing would be 1-1/4 or less. In general, the longer the wires in terms of wavelength the greater should be the reflector spacing if maximum concentration is to result.

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On page seven the statement is made that the transmission line feeds energy to a "U" shaped loop one half wavelength long. This adjustable loop is usually not one half wavelength long. The object of the loop is to complete the tuning of the antenna wires by making the total effective tuning length of each wire of the "V" equal to an odd number times a quarter wavelengths. The effective radiating length is the length of the wire of the "V" only, as the "U" loop is non-radiating, and can be any length. When the tuning is properly completed by the "U" the system presents a pure resistance load to a transmission line tapped on it and by tapping the loop at the correct distance from the short circuit strip this effective resistance can be made to equal the surge impedance of the line, the necessary condition for maximum efficiency of transmission.

I believe that it would be advisable to incorporate part of the explanations just made in the application so that there can be no doubt as to what the invention covers.

Yours very truly
P. S. Carter
P. S. Carter

PSC/MVN

P S Thanks for copy of Patent 1,623,996 which just came,
PSC

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, P. S. Carter
, Harry Tunick

May 24, 1930.

I am sending you herewith the United States patent application papers covering your invention originally described in our docket 4205, which you will kindly execute in the customary fashion.

A check for $1.00 covering the nominal consideration mentioned in the assignment is also attached hereto.

HT:AU
ENCS.

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Page Tightly Bound

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Form 235 Com. 2M 6-29

R. C. A. COMMUNICATIONS, INC.

INTERDEPARTMENT CORRESPONDENCE

TO: Mr. Harry Tunick, Patent Department
FROM: Mr. P. S. Carter
SUBJECT: Docket #4205

DATE June 5, 1930
FILE No. I

PATENT DEPARTMENT
RECEIVED
JUN 1930

Dear Mr. Tunick:

Attached you will find the patent ~~papers~~ covering the above docket, which I have executed as requested in your letter.

I note that no claims have been made for combinations of these units in broadside although this was described in more or less detail in the specification. Possibly the addition of claims covering these combinations is not necessary but it would seem that this would be as important as the claims covering combinations for concentration in the vertical plane and for producing uni-directional radiation. Upon inspection of the specification and the drawings I fail to find any errors.

Yours very truly

P. S. Carter

P. S. Carter

PSC/MVN

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UNITED STATES DISTRICT COURT

EASTERN DISTRICT OF NEW YORK

- - - - - - - - - - - - - - - - - - - -

RADIO CORPORATION OF AMERICA,	:	
Plaintiff,	:	
v.	:	Equity No. 7234
MACKAY RADIO & TELEGRAPH COMPANY, INC.,	:	
Defendant.	:	

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STIPULATION

IT IS HEREBY STIPULATED between the solicitors for the respective parties hereto that the following insertions, deletions, and changes appear in Red Pencil on the draft of Philip Staats Carter's Specification and Claims received in evidence as part of Plaintiff's Exhibit 43 (immediately following Mr. Tunick's memo to Mr. Carter of May 14, 1930):

Page 2, line 7 from bottom, after the word "transverse", the word -- plane-- is inserted; line 6 from bottom, the words "direction" and "vertically" are deleted, and after the inserted word "usually", the phrase --the vertical plane-- is added; line 3 from bottom the words "number of" are deleted and after the inserted word "preferably," the phrase --at least a-- is inserted; the "s" on the word "lengths" is deleted.

Page 3, line 4, the word --plane-- is substituted for "direction"; line 8 from bottom, "a vertical" is deleted and --the horizontal-- substituted; the phrase

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--of the vertical plane-- is inserted after the word "direction"; both insertions on line 8 are deleted in black pencil.

Page 4, fourth paragraph, line 2, after the word "vertically," the phrase --when the length of wires is of the order of 6 to 12 wavelengths.-- is inserted.

Page 5, line 16, "half wave" is deleted and --very short, (Hertz)-- substituted therefor.

Page 7, line 10 from bottom, the word "one-half" is deleted; line 9 from bottom, "wave length long" is deleted; line 7 from bottom, the phrase "are always at maximum potentials" is deleted; line 6 from bottom, "and" is deleted.

Page 8, line 6, "vertical" is deleted and --high angle-- substituted; line 13, the words "a vertical" are deleted and --the horizontal-- inserted, and after the word "direction", the phrase --of the vertical plane,-- is inserted; both insertions are deleted in black pencil; line 15, the phrase "number of half wave lengths" is deleted and --by any convenient spacing-- substituted; the words --at least-- are inserted after the word "preferably", line 16, after the word "apart", the following sentence is inserted: --The lower pair should be at least one-half wave length above ground.--

Page 9, line 7, the word "five" is deleted and --nine-- substituted therefor.

Dated, New York, N.Y.,
April 21, 1936.

Solicitors for Plaintiff

Solicitors for Defendant

83/99

PLAINTIFF'S EXHIBIT No. 44

M. Tunick
Patent Dept.

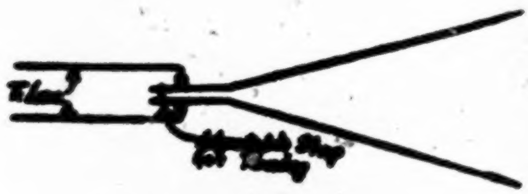
TRANSMISSION TESTS

MODEL "D" PROJECTOR

DESCRIPTION OF PROJECTOR.

The fundamental element of this system is a wire, having a length equivalent to several wave lengths, bent at the center so as to form a V and fed from a transmission line in a manner similar to that in common use in feeding a half wave dipole. The sketch below shows this scheme. If the angle included between the sides of the "V" is made of the correct value (this value depending upon the dimensions of the V according to rather complex law) an excellent bidirectional radiating unit is obtained, the maximum radiation taking place along the line bisecting the angle. If the length of each side of the V is made four wavelengths the correct value for the included angle is 50.4°.

Fundamental Element



Modifications to Permit Adjustments

If eight wavelengths, the correct value is 35°. In the system tested the length was seven and three quarter wavelengths.

The complete single bay of this antenna consists of two pairs of V wires. The two units of one pair are spaced apart a half wave length or more, one being above the other, and are fed in the same phase. The two pairs are spaced apart an odd number of quarter wave lengths along the center line and fed in the correct phase relation to produce a unidirectional system in whichever of the two directions it is desired to radiate. In the system tested (at a wavelength of 17.3M) the vertical spacing was one half wavelength and the spacing between pairs two and one-quarter wavelength. The system is suspended from six 80 foot poles. The sketch below shows the arrangement schematically. A two bay system, forming a "W" requires four additional poles or a total of ten.

Note Added
May 7/30

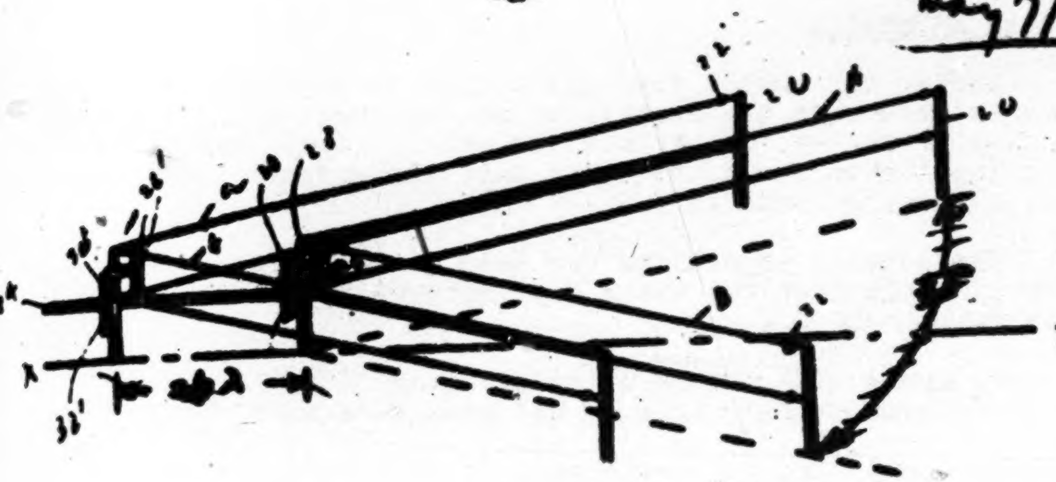


Fig 5

CHARACTERISTICS OF SYSTEM:

The two diagrams below show the theoretical curves of power distribution for one bay of this system in both the horizontal and vertical planes, the effects from ground being neglected.

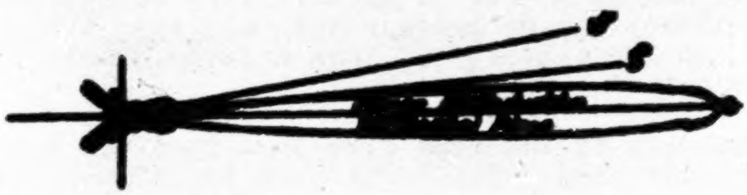


Fig 6

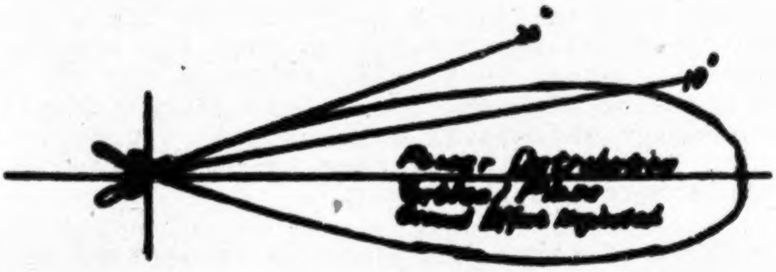


Fig 7

Carter
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H.T. May 8, 1930
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READINGS AT MARSHALL:

During the period from April 21st to May 1st, field intensity measurements were made at Marshall as we switched back and forth every five minutes between a doublet and the new antenna. During these tests the power input into the doublet and into the antenna was approximately the same, averaging about 13 K.W.

The general conditions for East to West transmission have been very poor the last few weeks but improved the last three days of these tests.

On April 21st and 22nd interference from the General Electric station at Oakland transmitting on the same wave made readings unreliable.

On April 23rd a large number of fair readings were obtained for the antenna but in all cases the doublet was either inaudible or too weak for accurate measurement.

The following day, April 24th, conditions were about the same excepting that readings for the antenna were extremely low at times.

On April 25th during the period from 11:30 to 2:40 EST the antenna readings were low but at all times measurable, while the doublet was at all times either inaudible or too weak to measure. However, from 2:40 until 5:00 when we stopped transmission reliable readings for both antenna and doublet were obtained.

On April 28th, 29th and 30th, we continued transmission until the signal had faded out at Marshall and on May 1st until 10:30 EDST at which time, we learned the next day, the signal had not faded out. On these last four days a large number of useful readings were obtained.

The results of the last five days readings are plotted on sheets which are attached. The curves are in terms of decibels gain with respect to one microvolt per meter. This system is used by the Bell Labs, and, after analyzing various methods of averaging results I am convinced that this method gives the most reliable results for average ratio to a doublet. It is equivalent to multiplying all ratios together and then taking the n-th root of the product (where n is the number of ratios) for the reason that the average logarithm of a set of numbers is equal to the logarithm of the nth root of their product. In this method high and low values of ratio have an equal effect upon the average whereas if arithmetical averages are taken one or two high ratios cause the average to be unreasonably high and very low ratios have little effect.

The results of these tests can be summarized as follows:

DATE	NUMBER OF USEFUL RATIOS	AVERAGE GAIN IN DECIBELS	PRODUCT	AVERAGE R TO DOUBL
Apr. 25	26	13.08	340	20.3
Apr. 28	74	17.74	1312	59.5
Apr. 29	72	18.70	1346	74.1
Apr. 30	66	19.20	1267.5	83.1
May 1	118	18.52	2184.4	71.1
TOTAL	356		6449.9	

OVERALL AVERAGE GAIN IN DECIBELS = 18.13

OVERALL AVERAGE RATI. TO DOUBLET = 65.0

DISCUSSION:

The resulting ratio obtained from these tests (65) is higher than expected. The calibration of the measuring device at Marshall has been checked and found to be OK. We can see no reason for the doublet not being efficient but we are putting up a new doublet further from the building for future tests. If we use a figure of 40 as a basis of comparison with other antennas we should be very much on the conservative side.

A close study of the curves will bring out several interesting facts:

In the larger proportion of the time the signals of the antenna and the doublet vary in synchronism. Allowance for the fact that the readings are taken five minutes apart should be made when these curves are scrutinized.

During these five days there are only two short periods where the antenna signal went so low as to become not measurable whereas the doublet signal was out a large number of times. One period when the antenna was out was during the eclipse of the sun in California. The other was in the early evening. Among several men in our company there is prevelent the idea that when a signal is out it is out regardless of the amount of power or of directivity used. These tests show the fallacy of this idea.

It will be noted that, in general the fluctuations in the received signal from the doublet are much greater than from the antenna. It is possible that this could be due to differences in directivity in the vertical plane.

COMPARISON WITH OTHER ANTENNAS:

A single bay harmonic antenna gives a ratio to a doublet of 16 and a two bay a ratio of 35. Using the conservative figure of 40 for one bay of the new Model D antenna the latter becomes 2.5 times as good as the one bay harmonic and 1.14 times as good as a two bay harmonic.

For operation at wavelengths around 35 meters it is proposed to build this new antenna 5 wavelengths long and thus do away with the necessity for intermediate towers and cross triatics. The directivity ratio for this length would be about 25. Such an antenna is one and one half times as good as a one bay harmonic. The one bay harmonic requires 10 towers costing $10,500 erected whereas the new type requires 6 towers costing $6,300. Thus we can obtain an antenna 60% better at a saving of $4200.

A two bay Horizontal Harmonic antenna requires 20 towers costing $21,000 whereas a two bay model D requires 10 towers costing $10,500 resulting in a saving of $10,500 in this case.

For wavelengths around 45 meters the savings would be greater.

"1/4

For wavelengths below 25 meters this new antenna is to be built on 80 ft. wood poles. For these shorter wavelengths the new system can be built for less than one fourth the cost of the equivalent vertical harmonic antenna. A two bay vertical harmonic antenna for 17 meters costs about $20,000 whereas the new type can be built for less than $5,000, resulting in a saving of $15,000.

The new antenna requires considerably less land area than the equivalent horizontal harmonic antenna but somewhat more than that required for the two bay vertical model excepting in cases where adjacent antennas can be directed so as to make the most efficient use of land.

RECOMMENDATIONS:

We now have on schedule for Bolinas and New Brunswick five horizontal harmonic antennas. It is recommended that in place of these antennas we substitute the new model D antennas. Four of these antennas lie in the band between thirty and thirty five meters and the saving in tower costs would be $16,800. The fifth is for a wavelength of 43 meters and the saving on this would be $6400. This makes a total saving on the five of $23,200. There would also be some additional saving due to the doing away with the cross triatics and rigging used in the harmonic antennas.

There are also on schedule six one bay vertical harmonic antennas, three for Bolinas and three for New Brunswick. If we substituted the new type in place of these we would have in each case an antenna two and a half times as good for less than half the cost resulting in a saving of about $30,000. However, before recommending such a change, particularly at Bolinas, a study of available land space should be made.

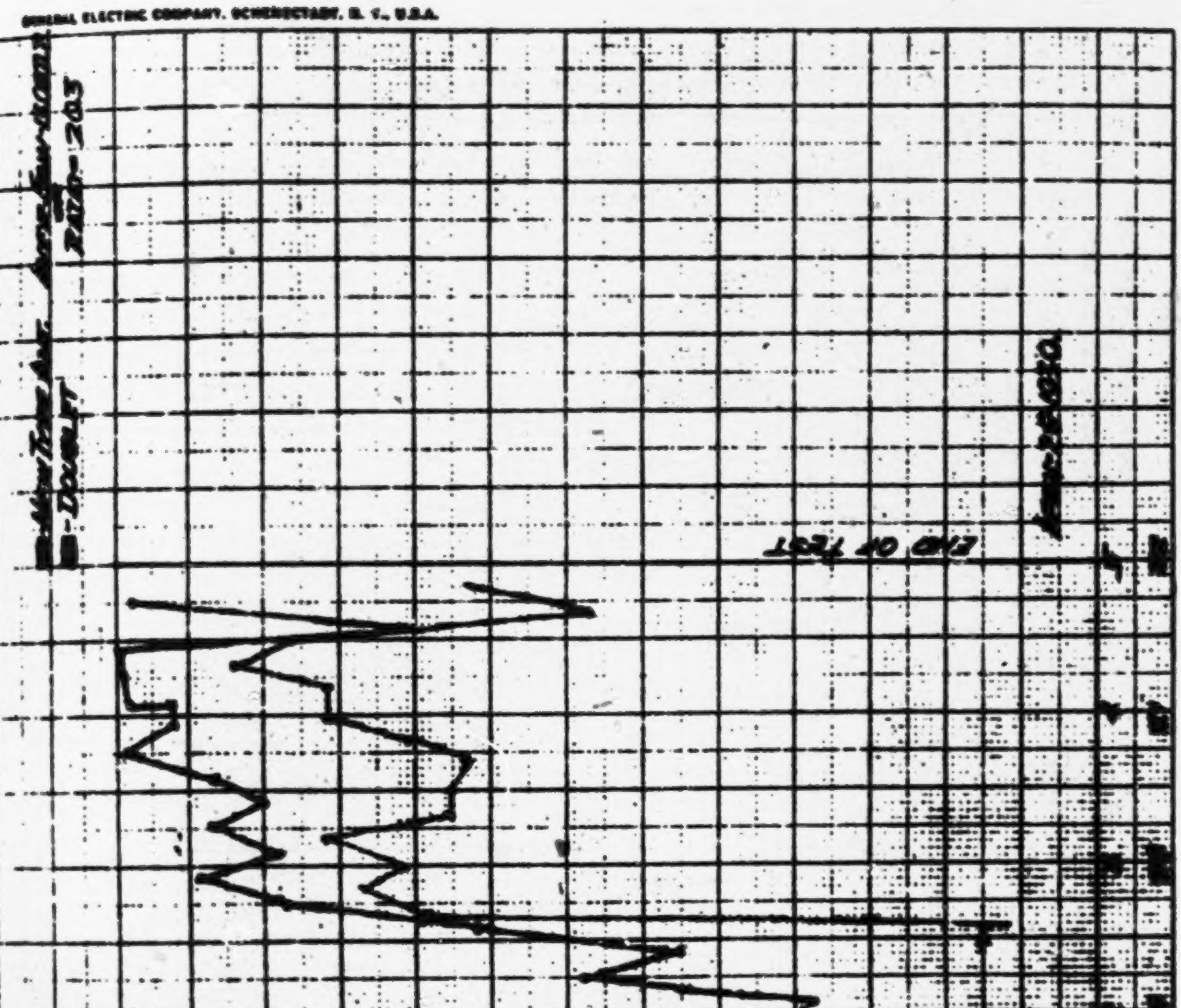
I believe that towers for these jobs are now on order. If such is the case the towers saved by the change can be used for either additional antennas or additional bays.

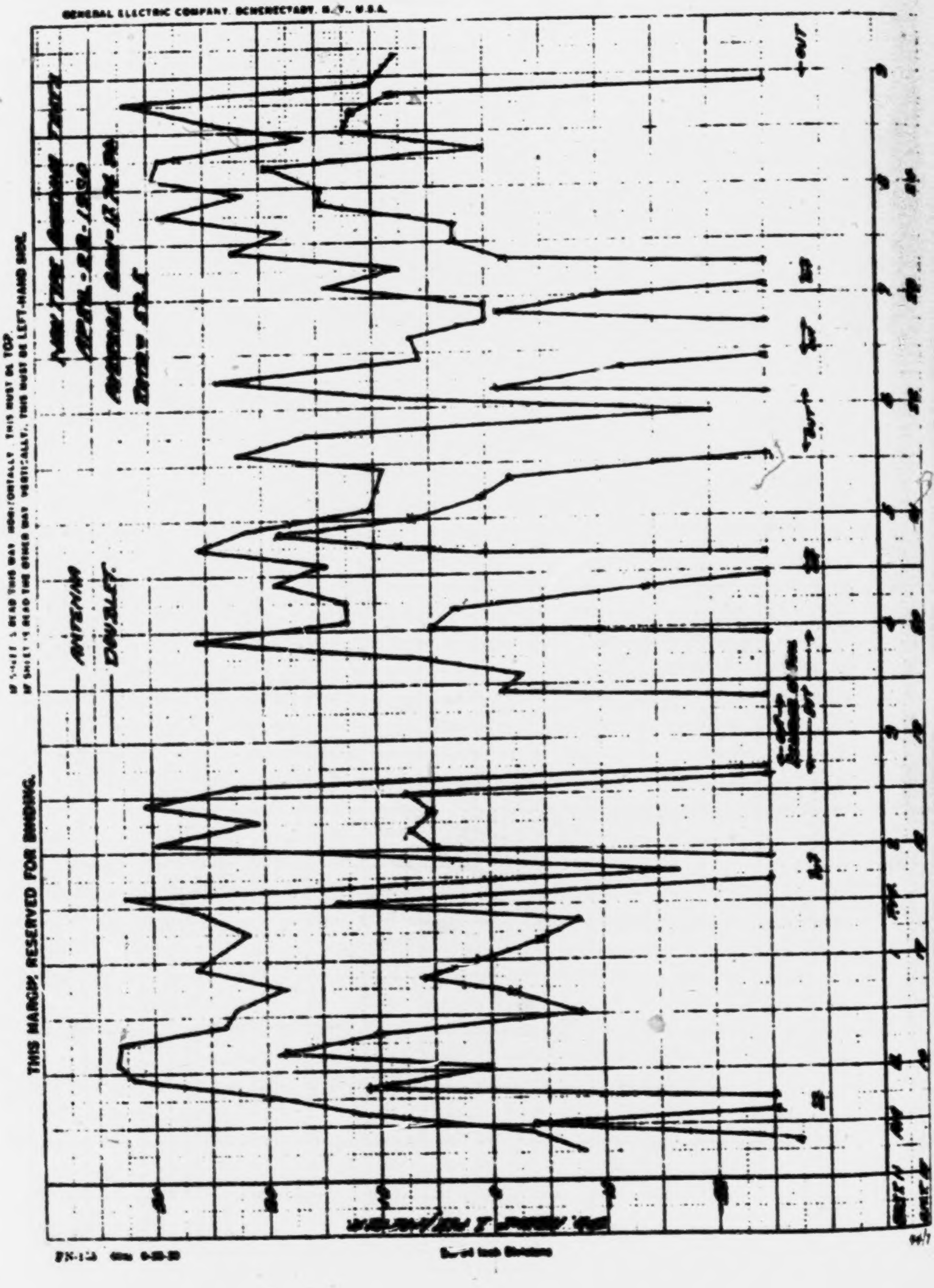
Copies to Mr. Taylor
Beverage
Shannon
Hallborg
Hansell
Patent Dept. (Mr. Tunick) ←

Rocky Point, New York
May 6, 1930
P. S. Carter
P. S. Carter

HP. May 8, 1930

GENERAL ELECTRIC COMPANY, SCHENECTADY, N. Y., U.S.A.

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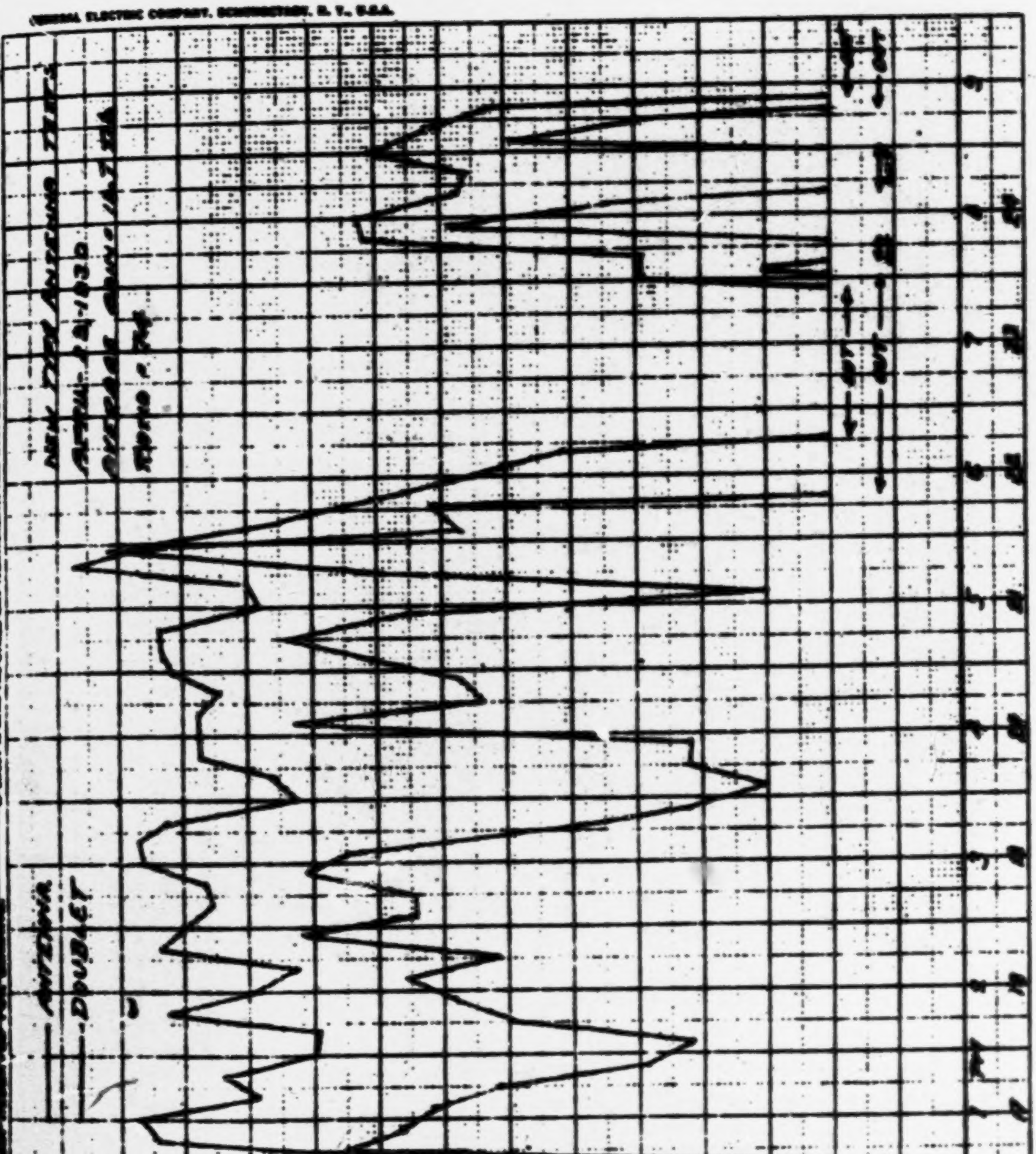
DOUBLET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ANTENNA
DOUBLET

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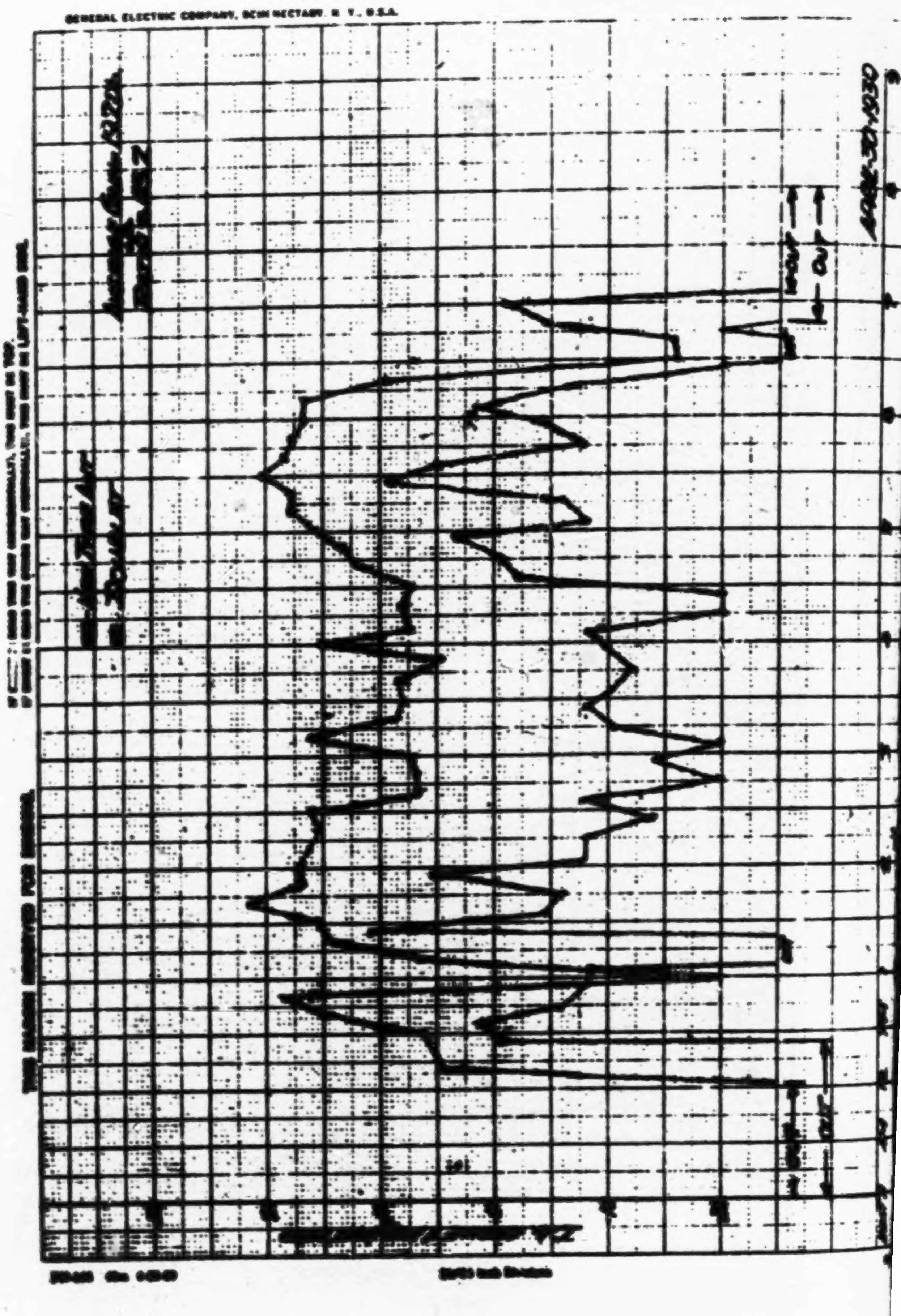

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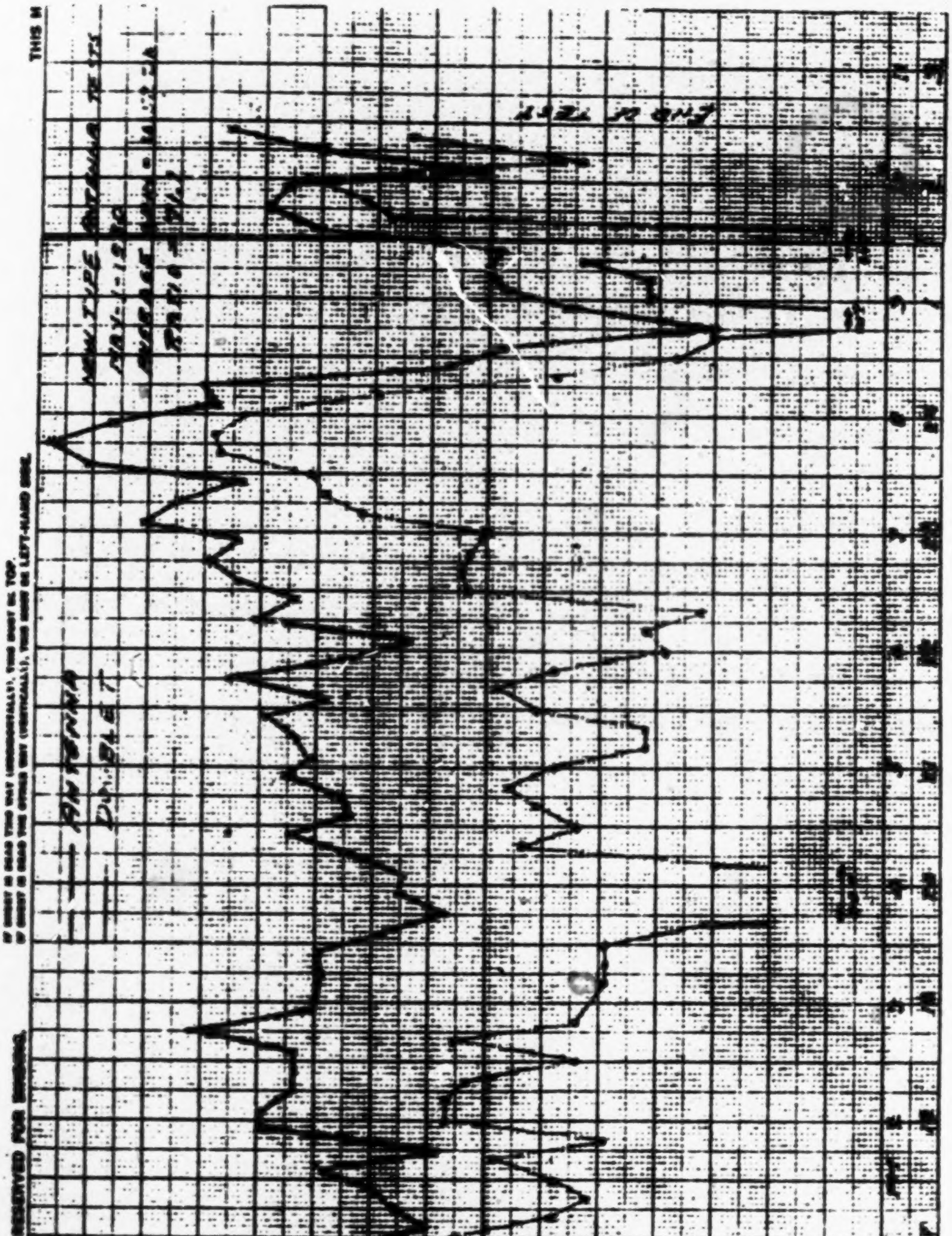


901-902

PLAINTIFF'S EXHIBIT No. 46

RD-1009

Mr. H. B. Morris
Mr. P. S. Carter

March 22, 1930
RD-1009

Experimental Antenna (New Type)

Dear Mr. Morris:

We appreciate the cooperation obtained from Mr. Ash and the men working under his supervision in connection with this job. Considering the fact that this antenna has been constructed almost entirly from reclaimed material and with incomplete drawings, the completed job is very satisfactory both in appearance and workmanship.

Yours very truly
P. S. Carter
P. S. Carter

PSC/MVN
Cc Mr. C. W. Hansell

PLAINTIFF'S EXHIBIT No. 46

Improved type directional antenna 1.

~~[illegible]~~ This idea in mind for last three or four months but not worked up until yesterday. After analyzing find much cleaner pattern than ordinary harmonic antenna and probably considerable improvement. Has advantage of being much simpler, stagger eliminated, and only takes 6 poles for equivalent of 2 bays whereas horizontal harmonic takes 20.

The fundamental unit is a harmonic wire odd number of half waves total length arranged in V and fed at apex as shown in Fig 1. This gives characteristic of form Fig 2 in plane of Fig 1.

Fig 1

l = odd no. half waves
angle is determined by length each half

Fig 2.

At ½ λ below this unit is suspended a similar unit [in plane] to cancel radiation below and above as shown in fig 3. In order to cancel back radiation a similar unit to Fig 3 is placed behind any odd number of quarter waves and fed leading in phase by same number of quarter phases as distance behind

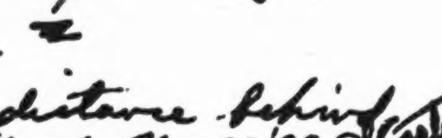


Fig 3.

continued

Witnessed by H.E. [illegible] Nov 27 '29 P.S. Carter

711
904

Improved type directional antenna

measured in number of quarter wave lengths. See Fig 4.

(Plan) n = odd integer
Fig. 4

Angles for maximum efficiency for a few lengths of wire are:

Total wire length wave lengths	angle α	length measured
$6\frac{1}{2}$	28.3°	$3\frac{1}{4}$ $\lambda/3$
$8\frac{1}{2}$	24.4°	$4\frac{1}{4}$
$10\frac{1}{2}$	21.9°	$5\frac{1}{4}$
$12\frac{1}{2}$	19.9°	$6\frac{1}{4}$
$14\frac{1}{2}$	18.4°	$7\frac{1}{4}$
$16\frac{1}{2}$	17.2°	$8\frac{1}{4}$
$20\frac{1}{2}$	15.5°	$10\frac{1}{4}$
$24\frac{1}{2}$	14.1°	$12\frac{1}{4}$
$32\frac{1}{2}$	12.2°	$16\frac{1}{4}$

Directional pattern in plane of Fig 4 with reflector is given by

$$\text{Power} \propto A_1^2 + A_2^2 - 2A_1A_2\cos\left(\frac{2\pi n}{4}\sin\alpha\sin\theta\right)$$

where θ is angle to X axis, A_1 is amplitude due to one-half length computed as function of $(\theta-\alpha)$ and A_2 is amplitude due to other half as function of $(\theta+\alpha)$. This characteristic fairly complicated particularly,

(continued)

Witnessed by
A. E. Goldstine

Nov. 27, 1928
J.F.B.

4/12

A further type of directive antenna. 3.

This system can be extended to an array of several units like Fig 5. to increase directivity by spacing by odd quarter waves along line X X' and any number of such systems can be placed side by side.

X  X'

Fig 5.

Nov 27 '29

Witnessed by H.E. Hallborg

R.S.C.

4413

PLAINTIFF'S EXHIBIT No. 47

Mr. Harry Tunick.
Patent Department
Docket 4205

Mr. H. H. Beverage
Mr. C. V. Hansell

May 7, 1930
RD-1009

RD-1009 - Tests of New Directive Antenna (Model D)

PATENT DEPARTMENT
RECEIVED
MAY - 8 1930
ANSWERED

Dear Mr. Beverage:

Attached you will find Mr. P. S. Carter's report on the results of tests recently made on a new type of directive transmitting antenna which he devised. As you will note from this report, the new type of antenna seems to be a decided improvement over the model B and C harmonic projector antennas. Its advantages are due to its improved directivity and a reduction in the number of poles or towers required to support it.

Although it is proposed to continue the tests by transmission on about one day each week for an extended period we believe the data already accumulated together with a consideration of the type of directivity obtained make it safe to recommend the new antenna for immediate commercial use. It is therefore suggested that consideration be given to substituting the new antenna for the original harmonic types in the present construction programs for Rocky Point, New Brunswick, Bolinas, Kahuku (Telephone) and other places.

The total net out of pocket cost of developing this antenna has been only about $3500 if we take out the second hand value of the material which we have left.

The total saving over the harmonic type of antennas, if all the new transmitters now scheduled were equipped with the minimum recommended directivity, would amount to at least $3,500,000. Therefore, we are confident that the value of this development is at least 1,000 times its out of pocket cost and is probably 500 times its total cost after adding incidentals and overhead.

The value of this one detail development in reducing construction costs should be sufficient to pay all salaries and field expenses for the whole Rocky Point Development force for a period of about six years.

Yours very truly
C. W. Hansell
C. W. Hansell

H.T. May 8 1930

CWH/NVN
Cc Mr. C. H. Taylor
Mr. H. H. Beverage
Mr. J. H. Shannon
Mr. H. E. Hallborg

Mr. P. S. Carter
Mr. Harry Tunick (Patent Dept.)

PLAINTIFF'S EXHIBIT No. 48

RD-1009

Mr. H. H. Beverage
Mr. C. W. Hansell

March 21, 1930
RD-1009

Comparison Tests on New Type of Harmonic Antenna

Dear Mr. Beverage:

We have just completed the construction of a modified type of horizontally polarized harmonic wire antenna which was suggested by Mr. P. S. Carter. If this antenna proves to be efficient, it should effect a considerable saving in construction costs in many cases by reducing the number of poles or towers required to support the radiators.

This antenna model is now being tuned up and checked by local measurements. As soon as this local work is finished we would like to make a comparison test between it and a plain doublet antenna for transmission to Marshall, California. In making these tests we would expect to follow the same procedure we have previously used for similar tests in which we alternated from one antenna to another at 5 minute intervals. For each interval we would send the number of the observation for signal strength reading so that Marshall could report the results of observations by reading numbers and thus avoid the possibility of a confustion in time. The frequency for which we have designed the antenna is 17,300 K.C. and we will use this frequency for making the comparison tests. We will use the call letters WEXT.

According to present indications, we will be ready to start the tests some time during the week of April 7th to 12th and will wish to continue observations for a period of at least three days. We would like to have the results of each day's tests reported back by service message as rapidly as possible. At the end of the three day period we would decide from the results obtained whether to continue testing or to discontinue temporarily for making modifications to the antenna. Probably we would wish to continue the test for a considerable period by transmitting one day each week for several months so that we could be sure that the results obtained were reliable and not due to some temporary atmospheric condition.

Could you please make arrangements with Mr. R. R. Beal to have his men at Marshall cooperate with us in making the tests? We will advise Marshall by service message the exact date on which we wish to start the tests.

Yours very truly

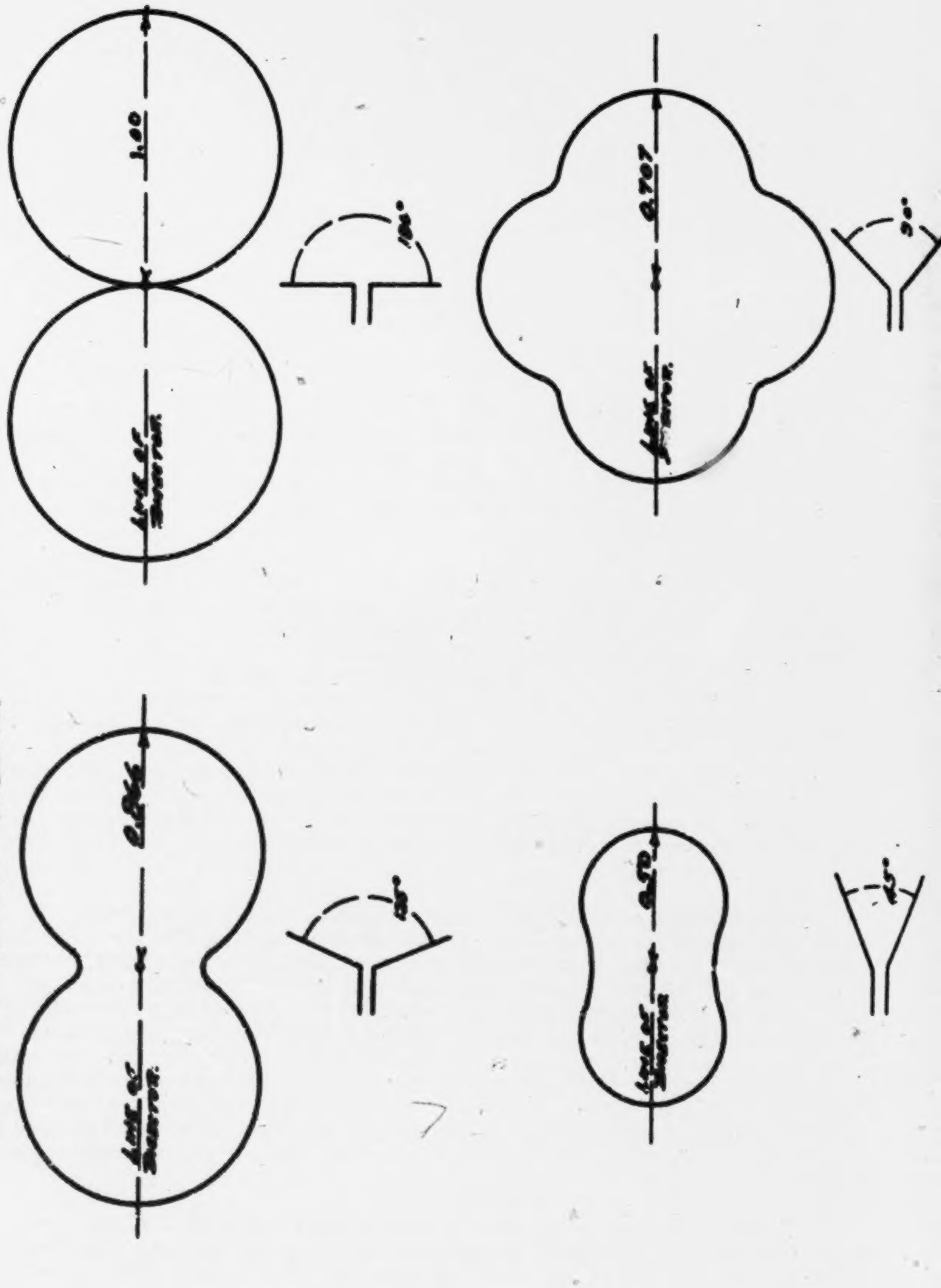
C. W. Hansell

C. W. Hansell

CWH/MVN
Cc Mr. C. H. Taylor

PLAINTIFF'S EXHIBIT No. 51

FIELD INTENSITY PATTERNS OF AN ANTENNA COMPOSED OF TWO QUARTER WAVELENGTH WIRES AT VARIOUS ANGLES.



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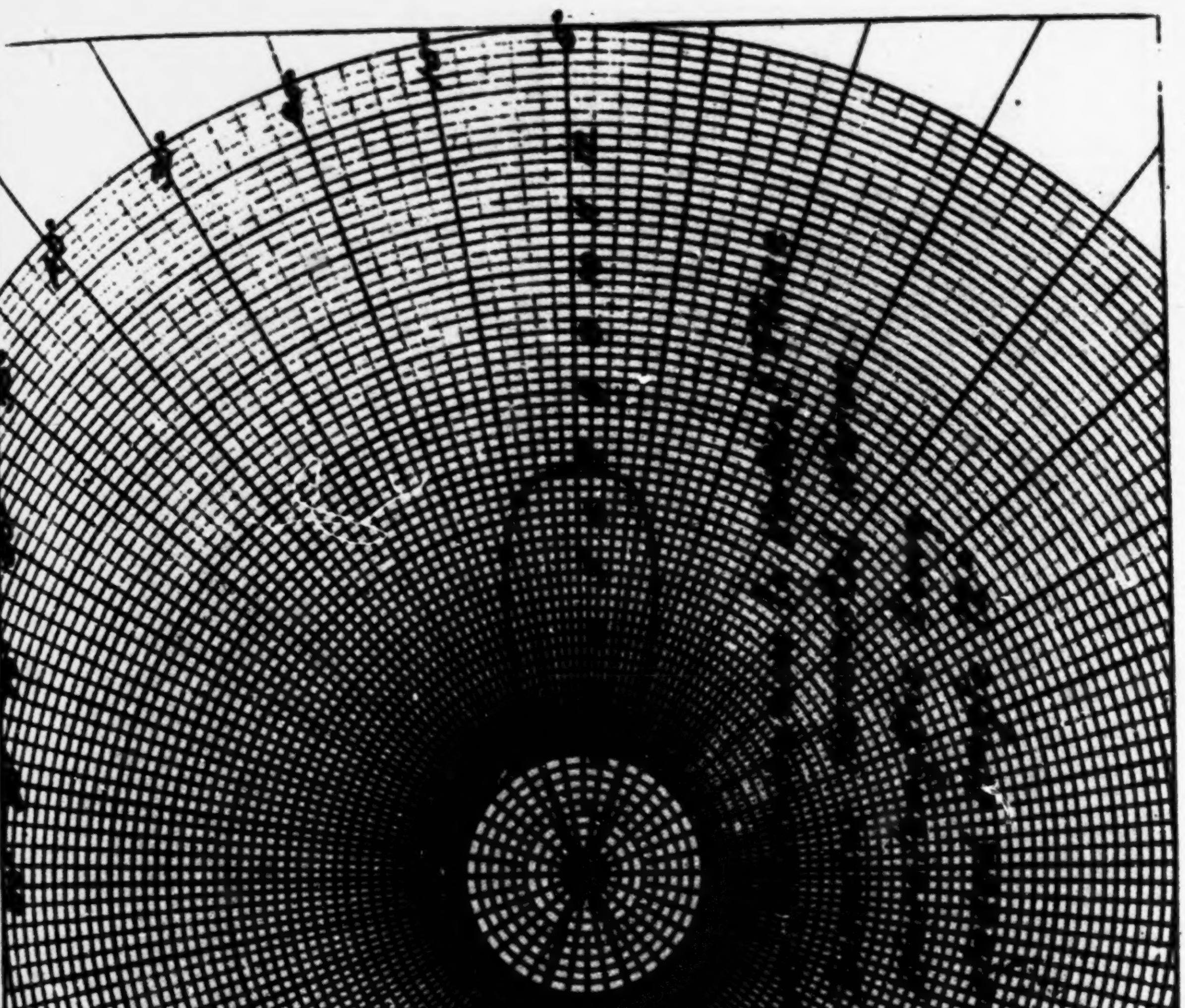

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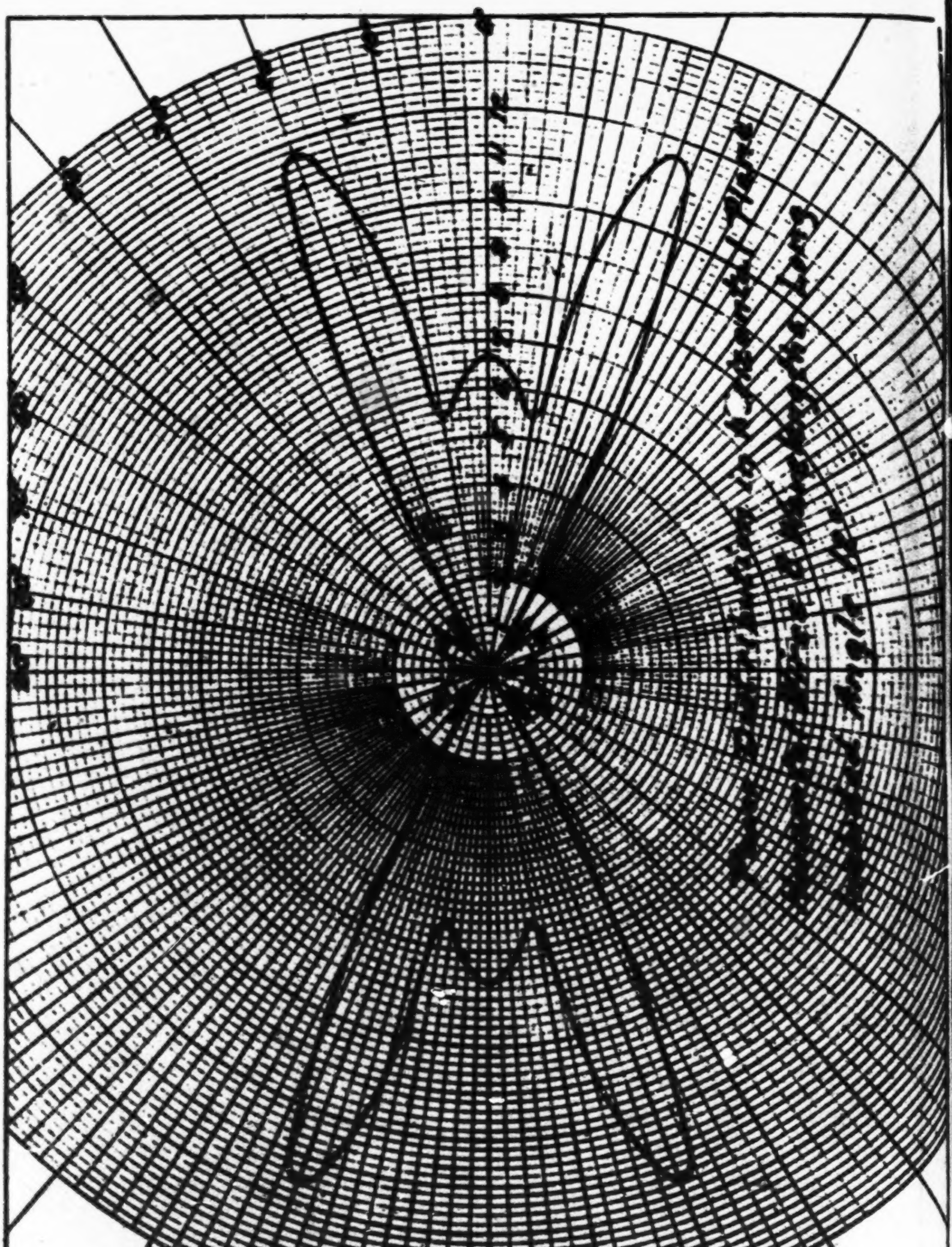

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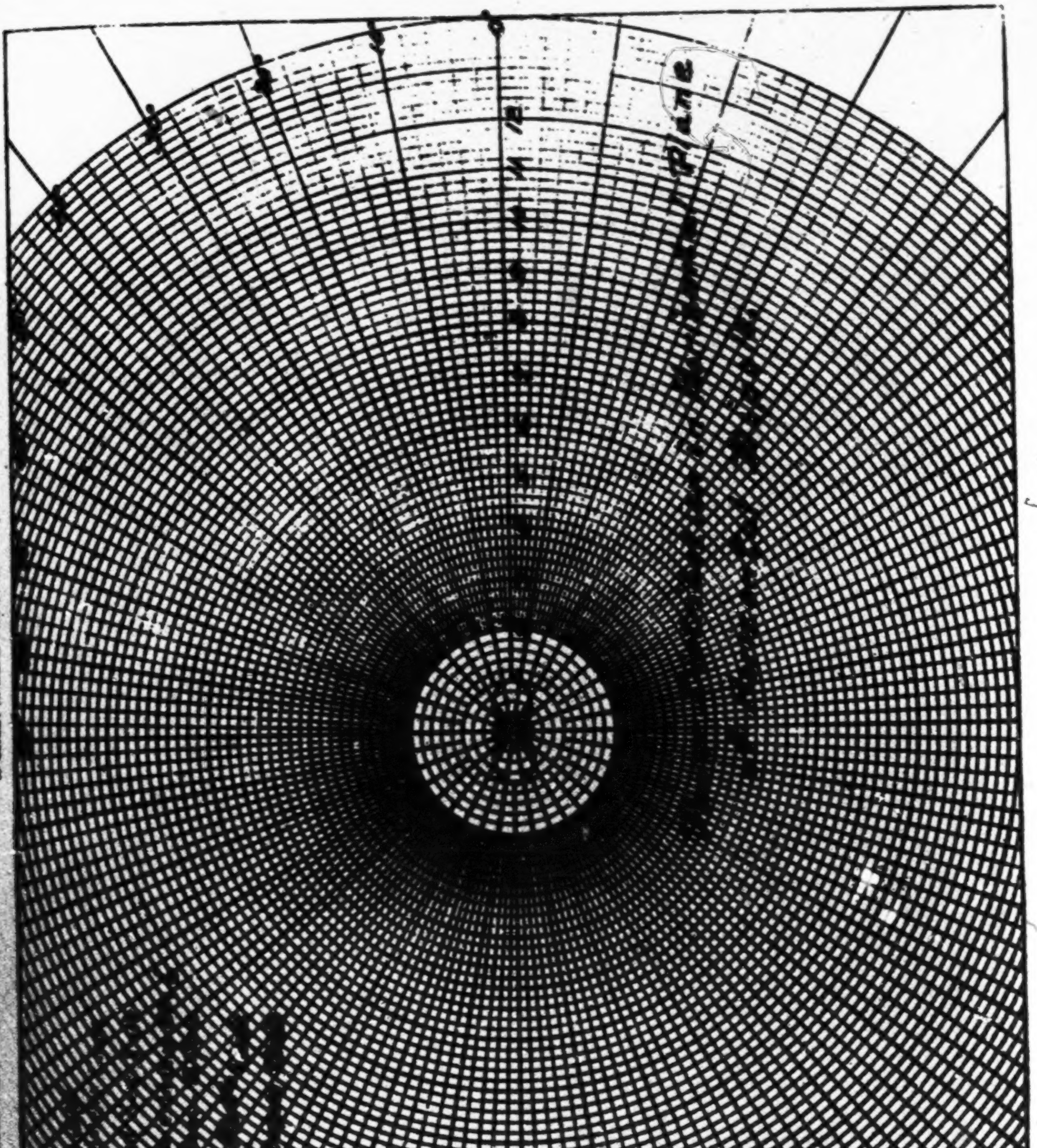

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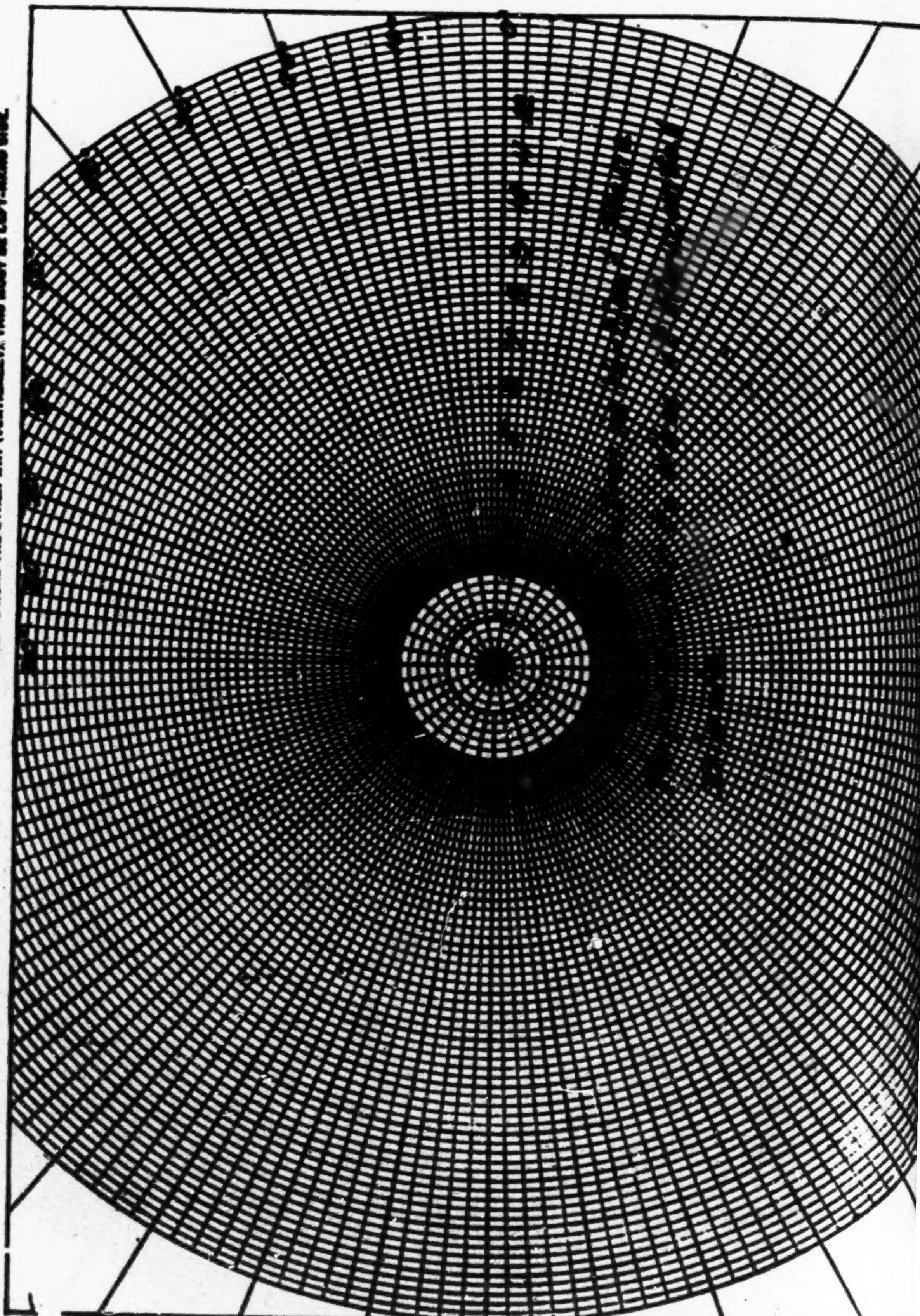

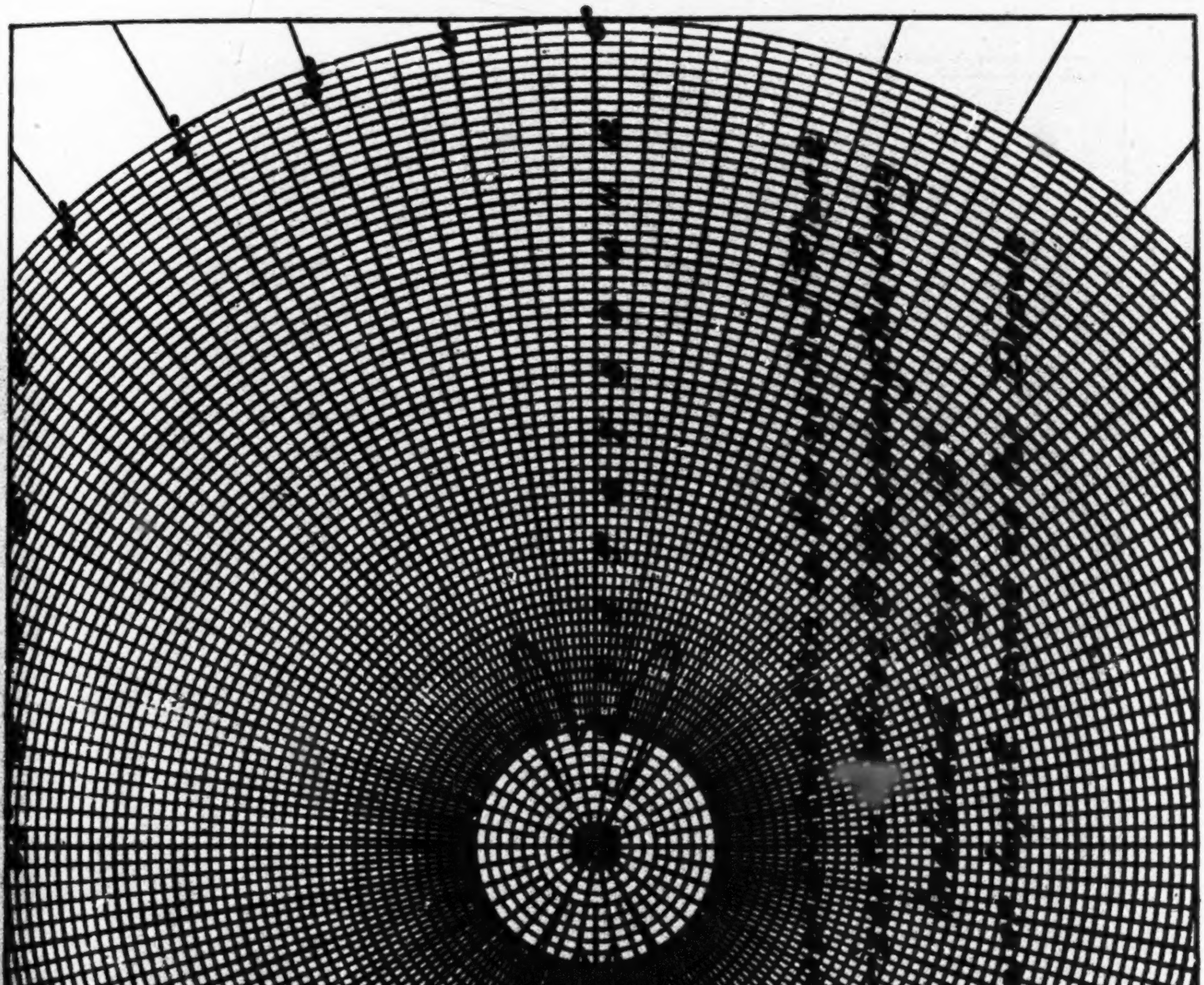

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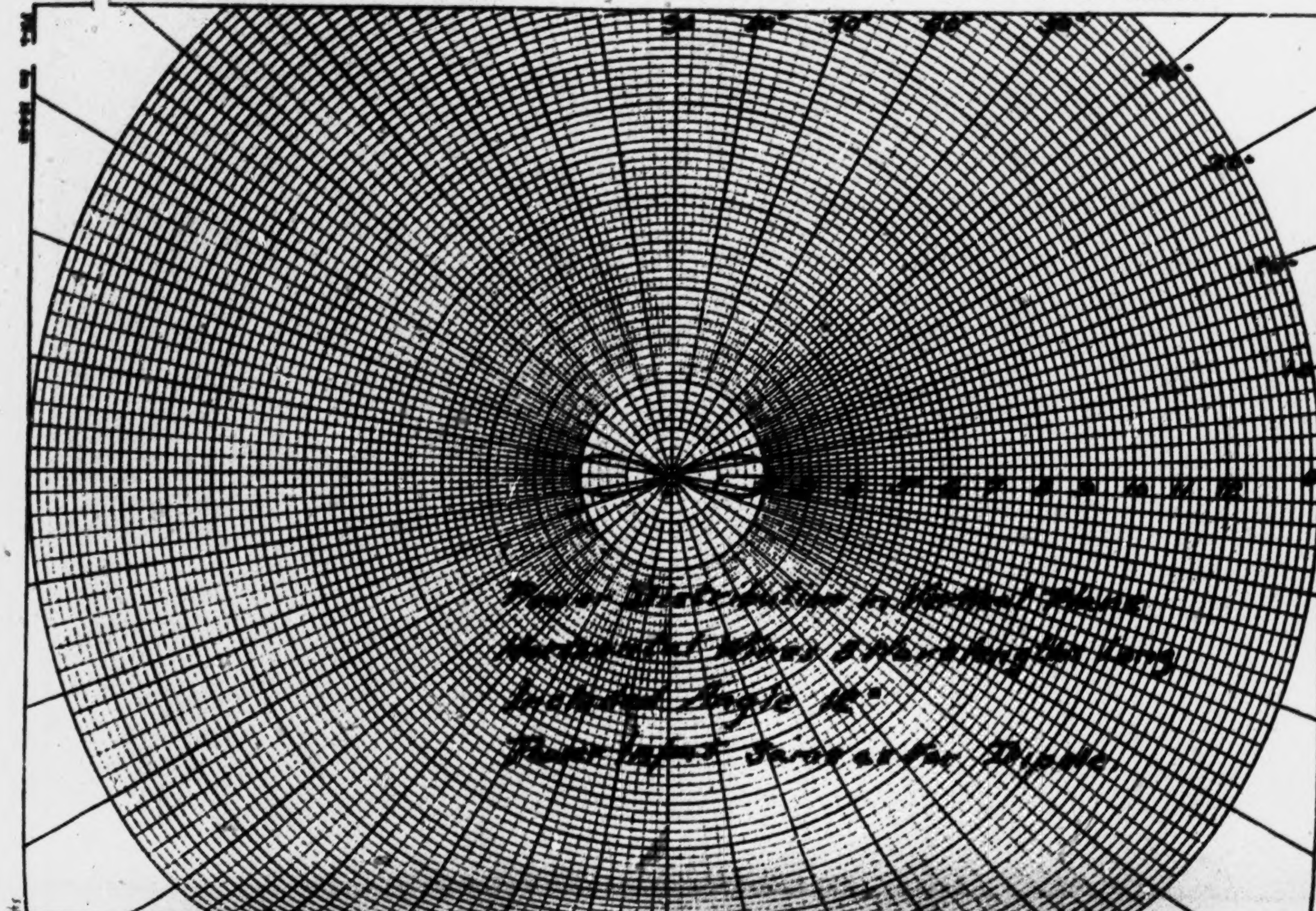
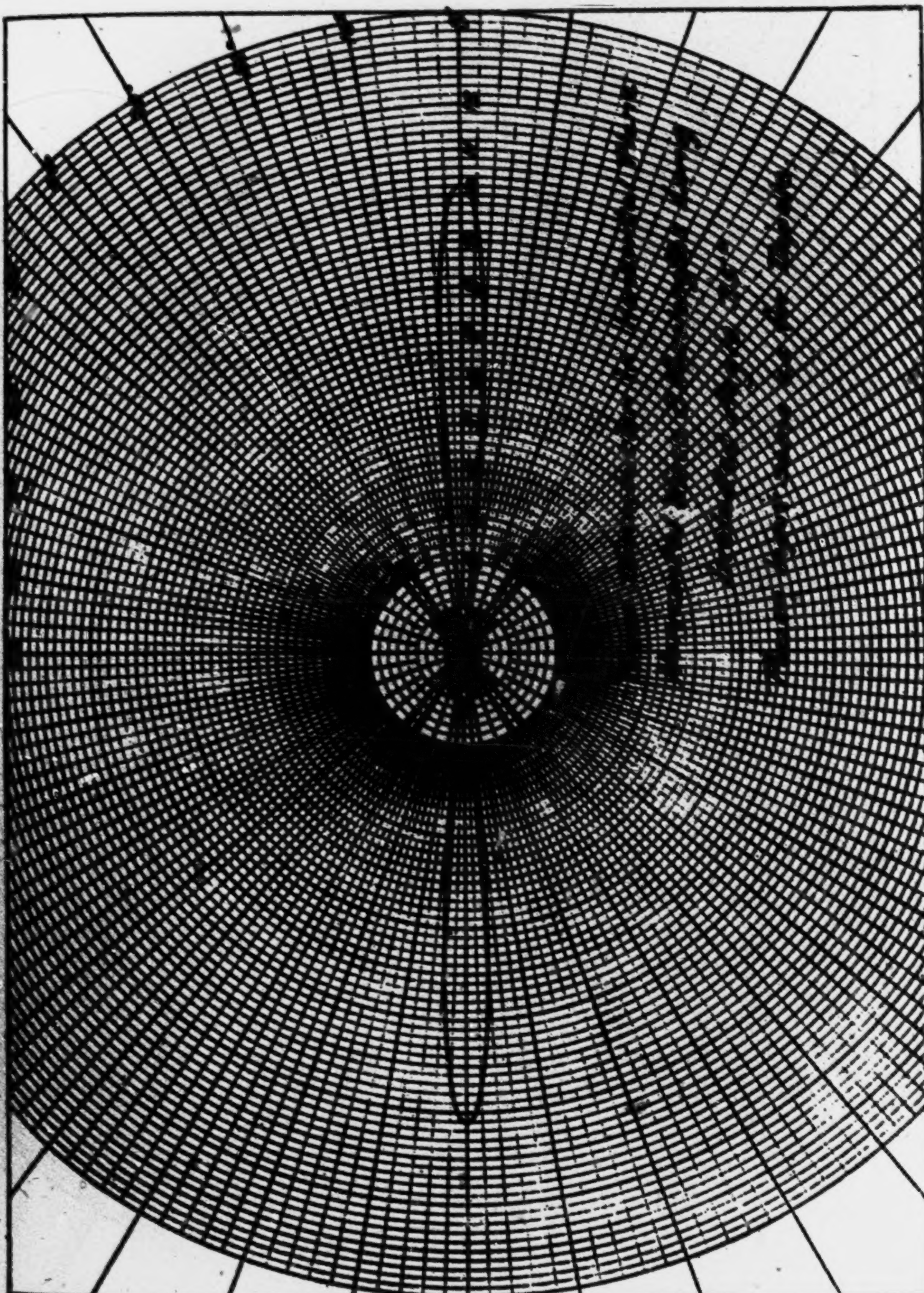

Power Distribution in Vertical Plane
Power Input Same as for Dipole



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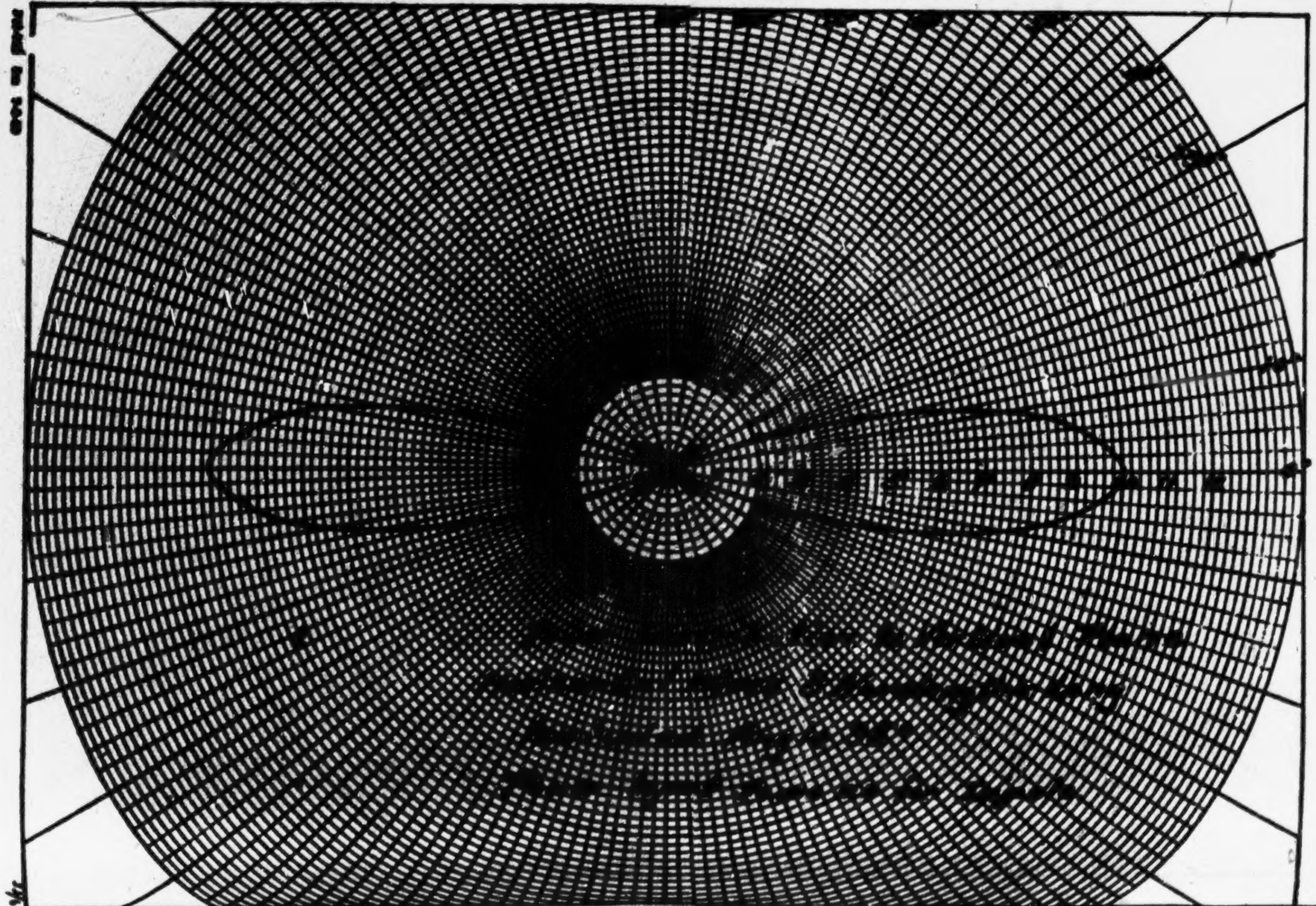

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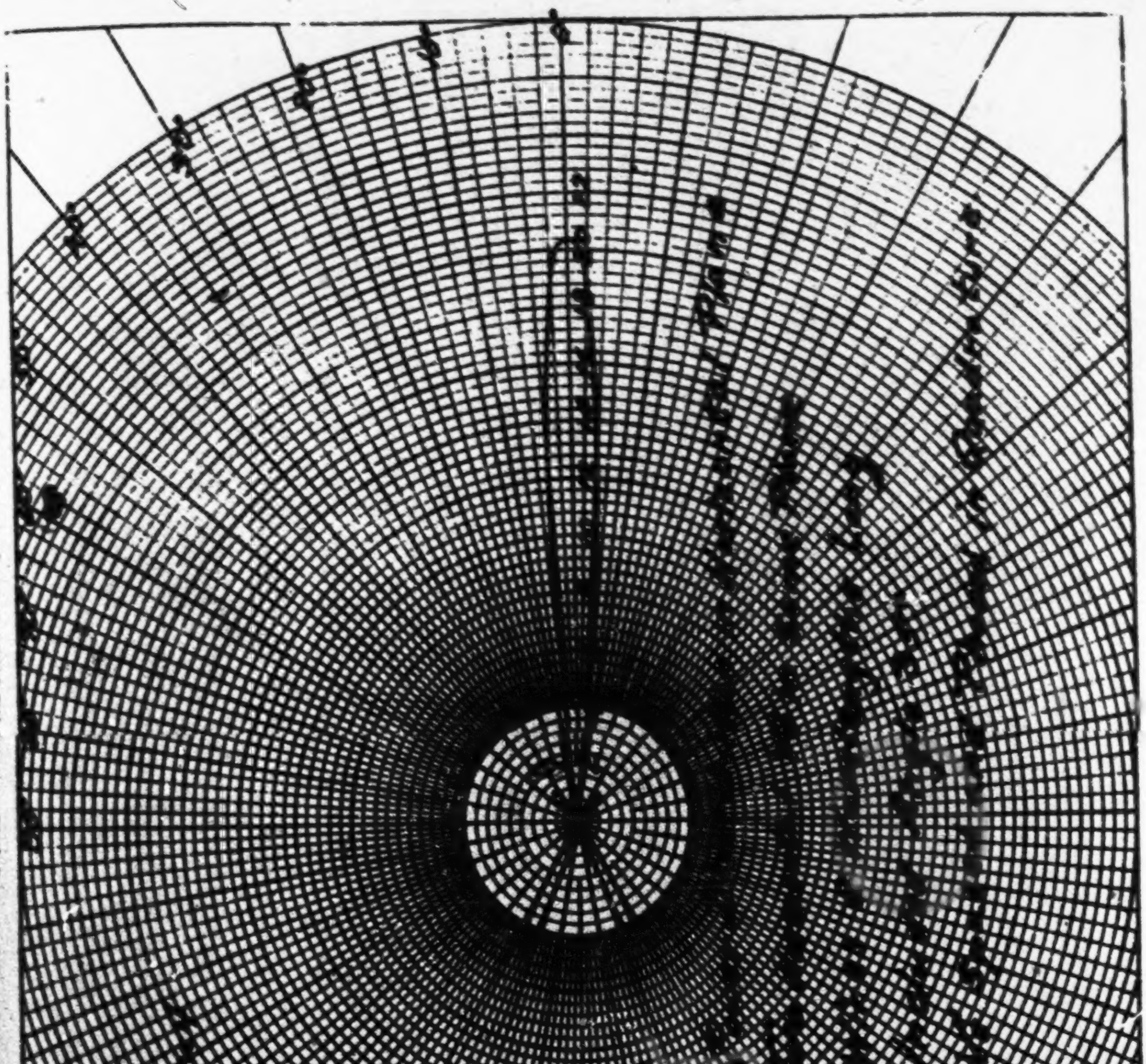

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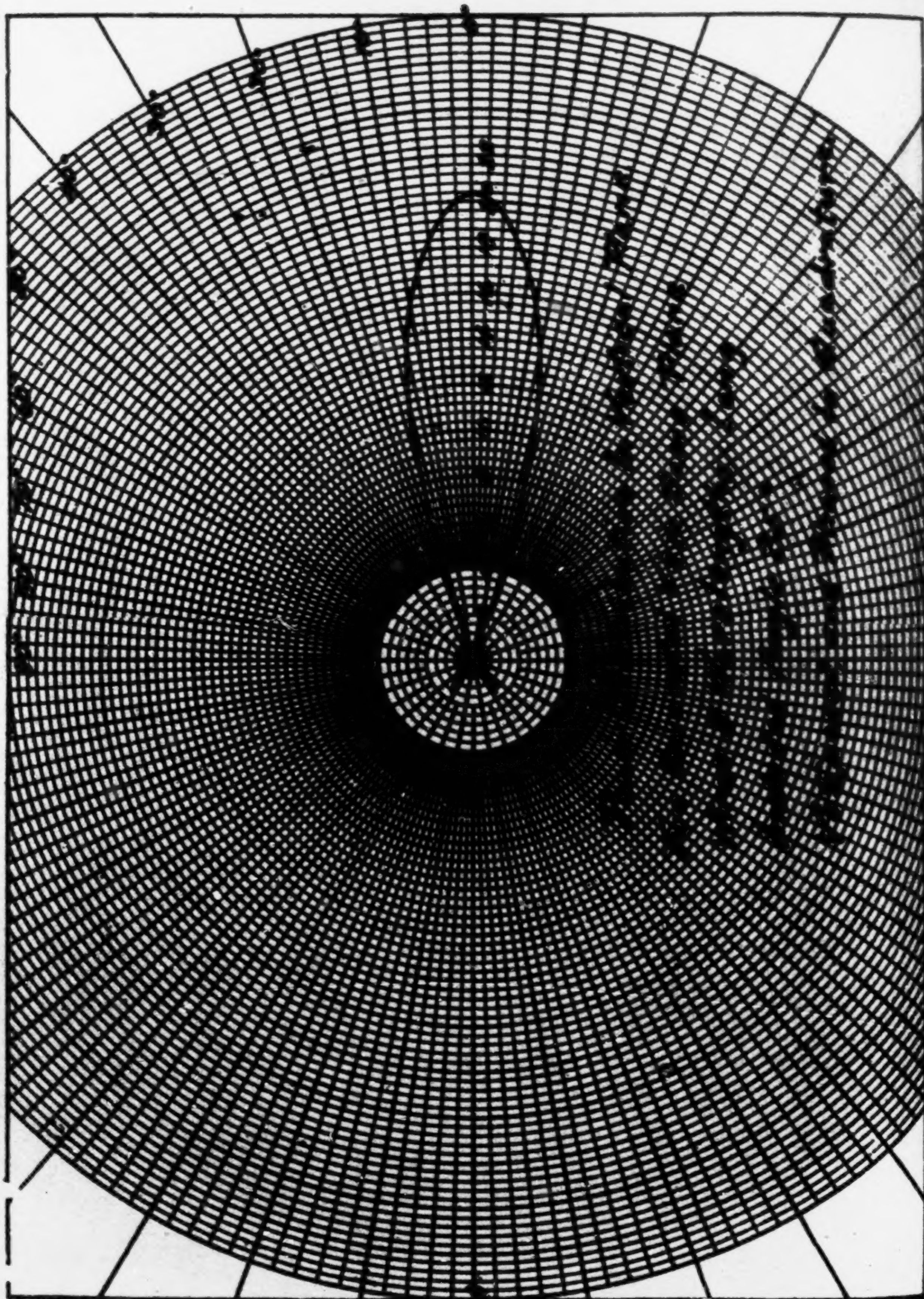

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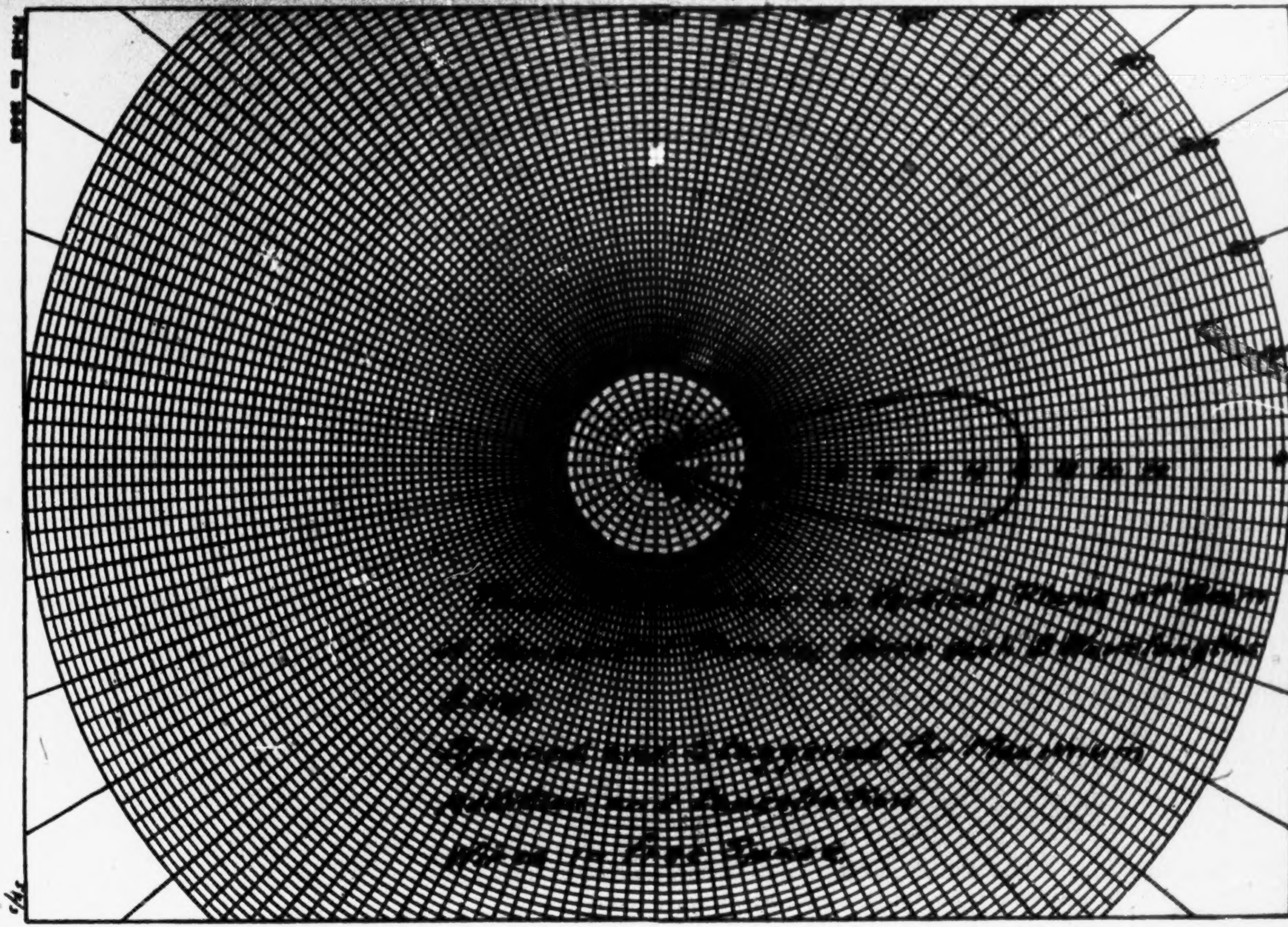

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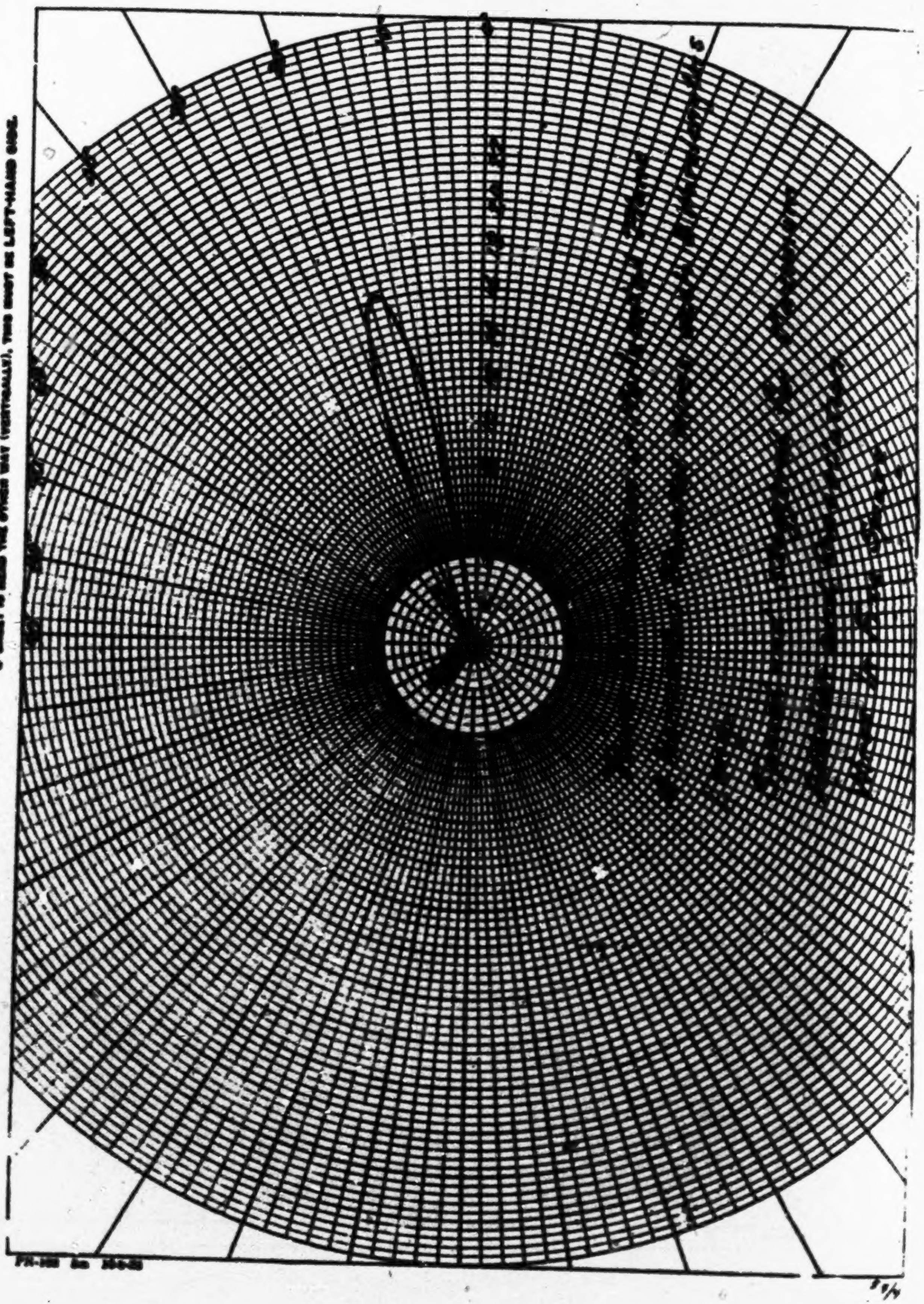


PLAINTIFF'S EXHIBIT No. 55

Plaintiff's Exhibit 55

Plaintiff's Exhibit 55 is a certified copy of an application for Letters Patent of the United States for "Improvement in Horizontal Vee-Type Antenna", filed by or on behalf of Edmond Bruce on February 3, 1931, bearing Serial No. 513,063. The British patent No. 392,201, issued to assignees of Edmond Bruce (constituting plaintiff's Exhibit 41 and reproduced above), was issued upon an application filed in Great Britain under the Convention and corresponding to the above-mentioned U. S. application Ser. No. 513,063 (plaintiff's Exhibit 55).

PATENT SPECIFICATION

Convention Date (France): April 29, 1924.

233,346

Application Date (In United Kingdom): April 29, 1925. No. 11,179 / 25.

Complete Accepted: July 29, 1926.

COMPLETE SPECIFICATION.

Improvements in or relating to Directive Aerials.

I, LUCIEN LEVY, of 66, rue de l'Universite, Paris, France, a citizen of the Republic of France, do hereby declare the nature of this invention and in what manner the same is to be performed, to be particularly described and ascertained in and by the following statement:—

The general type of aerials hitherto used is constituted by one or several conductors disposed in space and connected to one pole of one or several generators of high frequency currents, the other pole of which is connected to earth or to one or several wires constituting a balancing element. In certain cases, the wires of the aerial or those of the balancing element are connected by transverse wires which connect equipotential points together.

In these conditions, the aerial radiates a vertical electrical field which is accompanied, during its propagation, by earth currents which give rise to losses of energy.

In order to avoid these losses, it has been suggested to radiate the energy by means of vertical aerials comprising several wave lengths; in these conditions, the aerial radiates energy in the space comprised between two conical surfaces, the angle at the apex of which is less than 90°, and having the aerial for their axis.

In the case of ordinary aerials, if graphs are drawn with the distance from the ground of any point on the aerial as abscissa and the aerial current at that point as ordinate, one obtains either a curve or a cylindrical surface, that is, a surface generated by a curve remaining parallel to itself.

The present application has for its object improvements to aerials for the purpose of obtaining a more intense radiation of energy towards the receiving station, and to enhance the propagation of this energy with a minimum of loss.

According to this invention I provide a process for the emission at great distances of Hertzian radiant energy, characterised in that short waves are emitted (of wave length less than 1000 metres) with a horizontal electric field adapted to enhance reflection without loss on the Heavyside layer and on the ground and the propagation through space, the energy given out being maximum in the vertical plane perpendicular to the axis of the radiator, and being emitted in the form of an inclined pencil having the said plane for plane of symmetry.

For this purpose I use an aerial comprising two coplanar or colinear horizontal surfaces or groups of wires, connected to opposite poles of the generator at their inner ends, and fixed above the ground at a height of the order of from [illegible] to [illegible] of a wave length.

In the radiating surface (planes, for example) the current distribution is such that if one plots as ordinates, at every point of the surface, the current at that point, surfaces other than cylindrical surfaces are obtained. In other words, the surface being connected at two points to a high frequency source of potential difference, the current propagation takes place in two dimensions.

Owing to this double propagation, the directive action of the aerial is much greater, and instead of conforming to a three dimensional polar diagram in the shape of an anchor ring, as with ordinary aerials, the radiation takes place along a pencil only.

By the use of emitting aerials with a radiated electric field which is horizontal

instead of vertical, a more pronounced directive effect is obtained and the losses during the propagation are lessened.

A point extremely important, which necessitates the use of a horizontal electric field, is that the transmission of waves of short wave length to a great distance appears to take place by reflection on the Heavyside layer. It is easy to see that a polerised wave with a horizontal electric field is reflected without loss of energy on a horizontal conducting plane, while, on the contrary, a wave with a vertical field may fall under the incidence of Brewster, and in this case the reflected energy is much reduced. It is therefore logical to think that "fading" will not occur for waves with a horizontal electric field. Finally, it is proper to note that the atmospherics are very weak on a horizontal frame, consequently waves with a horizontal electric field must be particularly favourable for the elimination of parasites.

Horizontal aerials have already been utilised, but these aerials were employed with a large wave length and generally placed relatively very close to the ground and were of very large dimensions. The invention on the contrary, concerns the use of horizontal aerials of very small dimensions for the emission of waves of short wave length, situated at a height which is a considerable fraction of the emission wave length (½ wave, for example). Owing to this height and to the horizontality of the electric field, the losses in the neighbourhood of the emitting aerial are considerably reduced.

It is extremely important to raise the horizontal aerials to a suitable height, greater than ¼ of the wave length of the emitted wave. The effect of the conducting earth is to give an image of the aerial. If the aerial is in the neighbourhood of the ground, this image, which radiates a field inverse to that radiated by the aerial, partially neutralises the effect at a distance of the aerial. This drawback is avoided when the height of the horizontal aerial is comprised between ¼ and ¾ of the wave length. In this case, the radiation of the image and of the aerial are superimposed. It is easy to calculate, besides, the inclination to the horizontal plane, of the pencil of maximum energy density. These effects take place owing to the combination at a distance of the radiation of the aerial and of its image, the currents of which are out of phase by a quantity which depends on the height at which is placed the horizontal aerial. It must be noted that a reflecting element constituted by a wire, placed at the surface of the ground, will permit the phase of the currents radiated by the image and the inclination of the pencil of maxmum energy density to be varied as may be desired.

The radiation takes place, in these horizontal aerials, laterally and perpendicularly to the direction of the aerial when the latter is of the type employing a one-dimensional conductor, and obliquely in the plane of symmetry of the aerial when a radiating surface is employed, as distinct from a linear radiator.

Referring to the accompanying drawings, which illustrate as an example a manner of carrying out the invention:—

Fig. 1 shows one method of realising an elevated horizontal aerial according to the invention;

Fig. 2 is a graph showing the distribution of the currents in the aerial shown in Fig. 1;

Fig. 3 represents a horizontal radiating surface;

Fig. 4 is a plan view of the aerial 5—5—7—7 showing diagrammatically the formation of the waves;

Figs. 5, 5^a, 5^b, illustrate the arrangement of wires in a series constituting a conductor;

Fig. 6 shows in perspective the aerial 5—5—7—7;

Fig. 7 shows an alternative arrangement;

Fig. 8 illustrates the use of two planes adapted to act as electric reflectors.

The aerial shown in Fig. 1 is constituted by the plane consisting of horizontal wires 1 and 2 supported between pillars 3 and 4 by spreaders 6 and 8 insulated from the live wires by insulators 5 and 7. The wires 1 and 2 are connected by chains 14 of insulators. A high frequency generator 11 supplied the energy to the aerial, at the points 12 and 13, by means of the pair 9—10.

Although at a first glance this aerial appears similar to the vertical T-shaped aerial, it is totally different therefrom inasmuch as the two branches of the T are insulated from each other.

In operation, the arrangement functions as follows:

The wires 9 and 10 of the feeding-line are the seat of high frequency currents in inverse direction, according to the arrows 16 and 17, and, consequently, the vertical radiation of the pair 9—10 is nil. The portion 1, 2 alone radiates, laterally and in the direction 15, a horizontal electric field h and a magnetic vertical field H.

The reception of these waves which

have a horizontal electric field can be made on a horizontal aerial, disposed in a parallel direction to the field *h* and which can be either elevated or at ground level. Owing to the inclination of the magnetic field to the direction of propagation, vertical or horizontal aerials directed in a perpendicular direction to that referred to above can be also used.

If a receiving frame is used, this must be generally placed in a horizontal plane, but reception will also be possible on a vertical frame placed perpendicularly to the direction from the emitting to the receiving station.

In Fig. 2, at each point of the wires 9, 10, a perpendicular has been plotted, proportional to the current at that point at a given instant.

It is seen that the length of the pair 9—10 is half a wave length and that the lengths of the portions 1 and 2 are a quarter of a wave length. Other distributions could have been chosen besides the one above described. Any desired distribution can be obtained by suitably combining with the aerial artificial line elements. Particularly, any particular distribution can be avoided by constituting each of the conductors 9 and 10 (or even 1 and 2) by series of wire elements constituting capacities disposed in succession to one another.

Fig. 5 illustrates an arrangement in which the conductor is composed of a series of overlapping wires a, a^1, a^2 . . . . . ;

Fig. 5^a shows an arrangement in which the elementary wires a, a^1, a^2 . . . . . are spaced end-on, and Fig. 5^b shows an arrangement in which the elementary wires a, a^1, a^2 . . . are separated by capacities b, b^1, b^2 . . . . .

Figs. 3 and 6 illustrate an aerial formed as a horizontal surface which radiates waves with a horizontal field and forming a pencil with a direction inclined to the horizontal, thereby obtaining, in one of the emission surfaces, the distribution of current shown by the graph of Fig. 4. In Fig. 6 this surface is represented in perspective and radiates its energy in the direction of the arrow 19 with a maximum of radiation in the vertical plane of symmetry 20.

The radiating surface is supported by the four pillars 3, 3 and 4, 4, by means of the four insulators 5, 5 and 7, 7. The generator 11 puts in a high frequency current at the points 12 and 13. If the current intensity at any point along 5—7 and 5—5 is plotted as ordinates (Fig. 4), curves 23 (each of a quarter wave length) and 24 (two loops d and d^1 of a quarter wave length each) are obtained, and similarly along line 7—7. It follows that the high frequency currents proceed on the surface 5—5—7—7 in such a manner that a half wave length regime 16—17 is established (formed of the two quarter wave lengths 23) and travels from front to back (arrow e) along the depth of the plane 5—5—7—7. The dimensions of the phase from front to back are such that the propagation from front to back comprises several quarter wave lengths. In a similar manner, the front to back propagation on 5—5 comprises several quarter waves d, d^1, and this propagation occurs along the whole breadth of the plane of the aerial. A double stationary regime is therefore present, a half wave length one, parallel to the arrows 16, 17, and another of several quarter wave lengths, parallel to the arrows 21 and 22.

Owing to the propagation in the direction 16, 17, the radiation energy is concentrated in the plane 20 and owing to the propagation in the perpendicular direction, it is limited to a pencil inclined to the horizontal. It is easy, besides, to adjust the inclination of the pencil by varying the distribution parallel to the plane 20 (Fig. 3), for example by inserting inductances or capacities placed at ground level, connected to the surface by conductors parallel to 9 and to 10. Fig. 7 shows this variation in which inductances or capacities f or impedances z are inserted in the conductors connecting the aerial to earth.

It should be mentioned that the radiating surfaces may comprise a larger number of principal axes according to which the propagation takes place, notably one could contemplate three axes forming a trihedron; one can in this manner obtain radiating beams as fine as desirable.

Similarly, these surfaces may be disposed in any direction and may radiate an electric field of any inclination; they can also act as reflectors. As an example, Fig. 8 shows the use of two planes g and h, perpendicular to the aerial, and adapted to act as electric reflectors.

The use of the arrangements described above is applicable to all wave lengths, but it should be pointed out that their results are particularly important for short wave lengths, less than 1000 metres in length, notably for wave lengths of 100 and 200 metres. The radiating planes could also be constituted by groups of metallic tubes or any other conductors.

Having now particularly described and ascertained the nature of my said inven-

tion and in what manner the same is to be performed, I declare that what I claim is:—

1. A process for the emission at great distance of Hertzian radiant energy consisting in the emission of short wave length (less than 1000 metres) with a horizontal electric field permitting the reflection of the energy on the Heaviside layer with a good efficiency by means of an aerial stationary with respect to the earth, comprising two co-planar or co-linear horizontal surfaces or groups of wires connected to opposite poles of a high frequency generator at their inner ends and fixed above the ground at a height of at least ¼ of a wave length.

2. In a process for the emission at great distances of Hertzian radiant energy, as claimed in Claim 1, an aerial as claimed in Claim 1, in which the length of each co-planar or co-linear element is a quarter wave length or a multiple thereof.

3. In a process for the emission at great distances of Hertzian radiant energy, as claimed in Claim 1, an aerial as claimed in Claims 1 and 2 in combination with a reflector, placed at ground level and parallel to the aerial.

4. In a process for the emission at great distances of Hertzian radiant energy as claimed in Claim 1, an aerial as claimed in Claims 1 and 2, in combination with vertical frames perpendicular to the direction joining the sending and the receiving stations.

5. In a process for the emission at great distances of Hertzian radiant energy, as claimed in Claim 1, the aerials, substantially as described and as illustrated in the accompanying drawings.

Dated this 31st day of March, 1925.

MEWBURN, ELLIS & Co.,
70/72, Chancery Lane, London, W.C. 2.
Chartered Patent Agents.

Redhill: Printed for His Majesty's Stationery Office, by Love & Malcomson, Ltd.—1926

233,346 COMPLETE SPECIFICATION

[This Drawing is a reproduction of the Original on a reduced scale]

Fig. 1

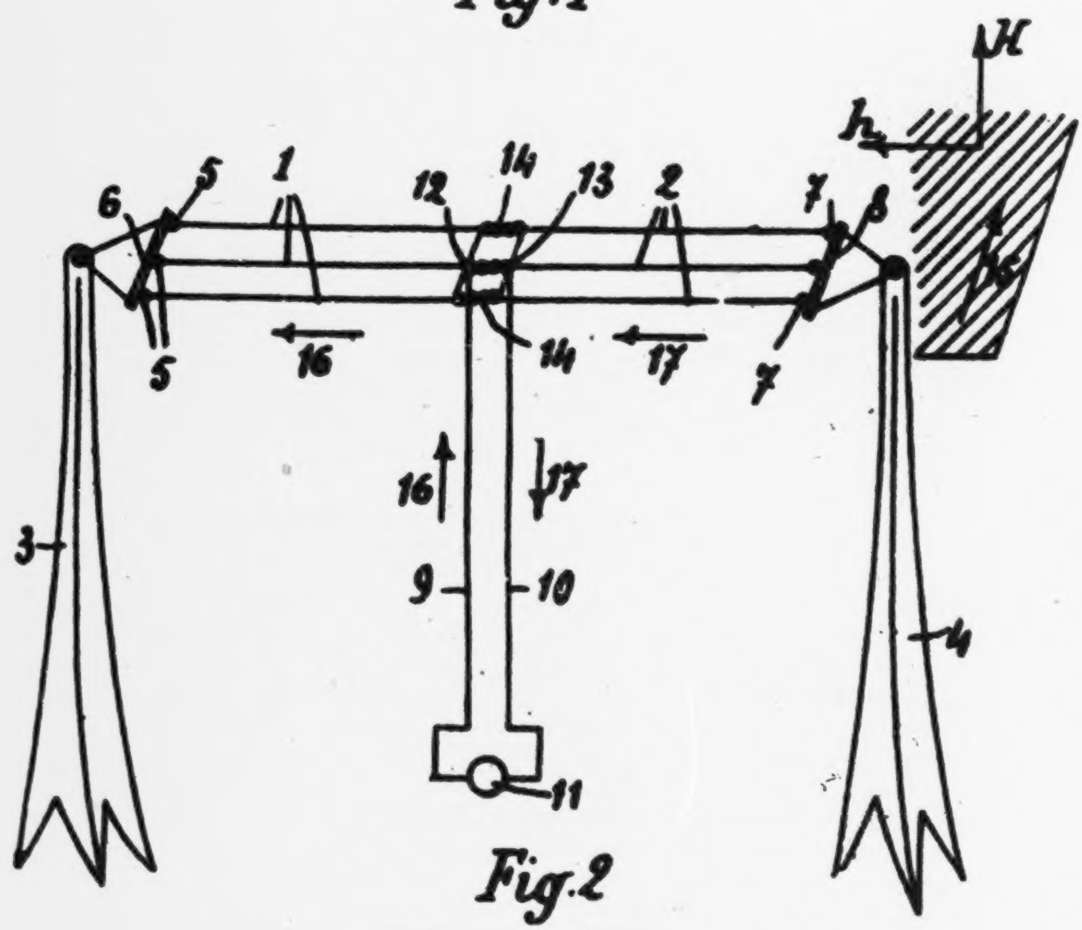
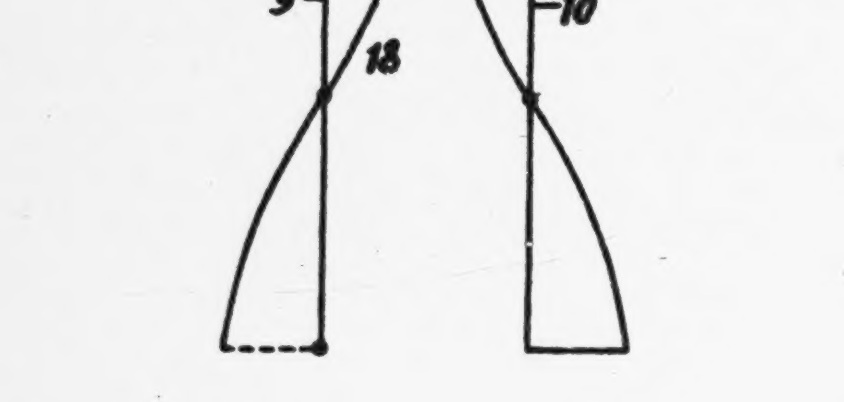


Fig. 2



233,346

2 SHEETS
SHEET 2

Fig.3

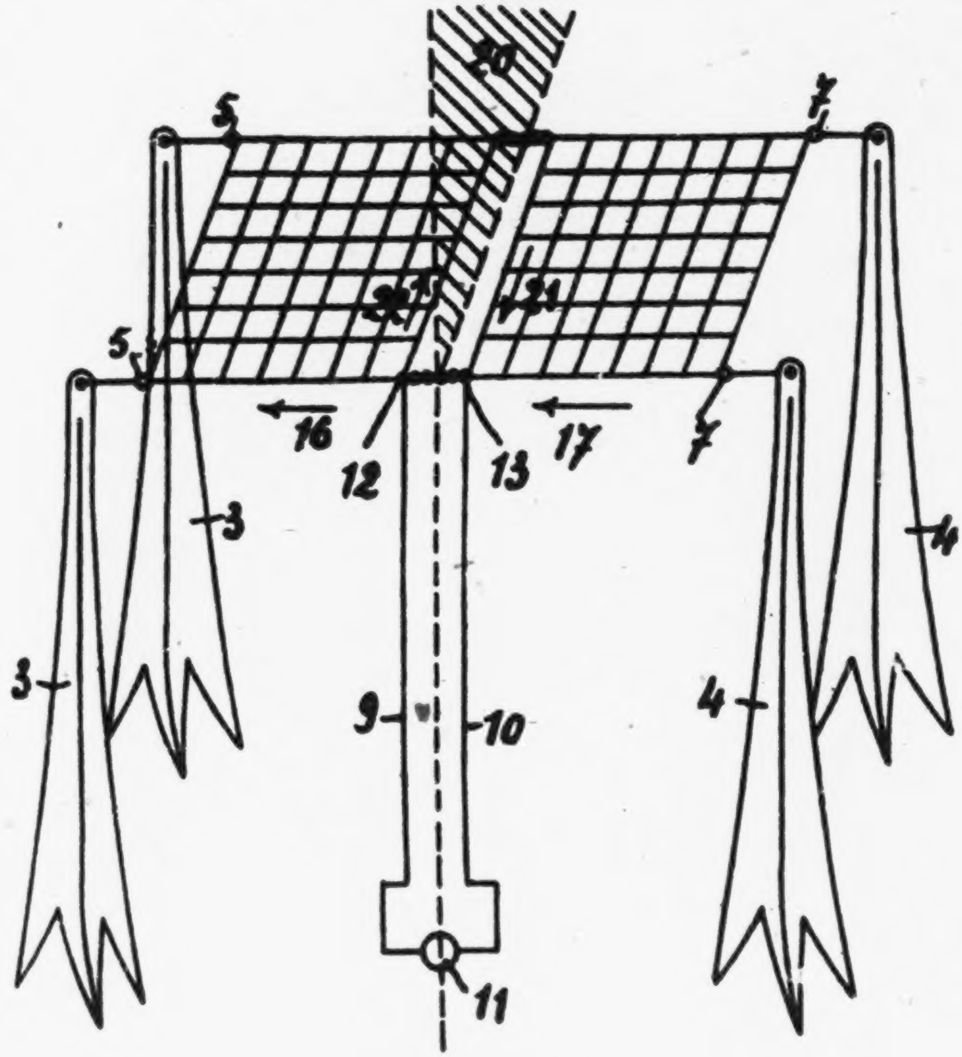
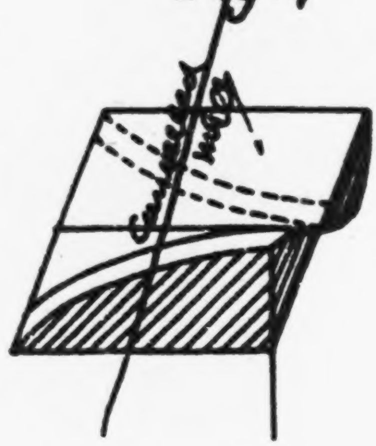


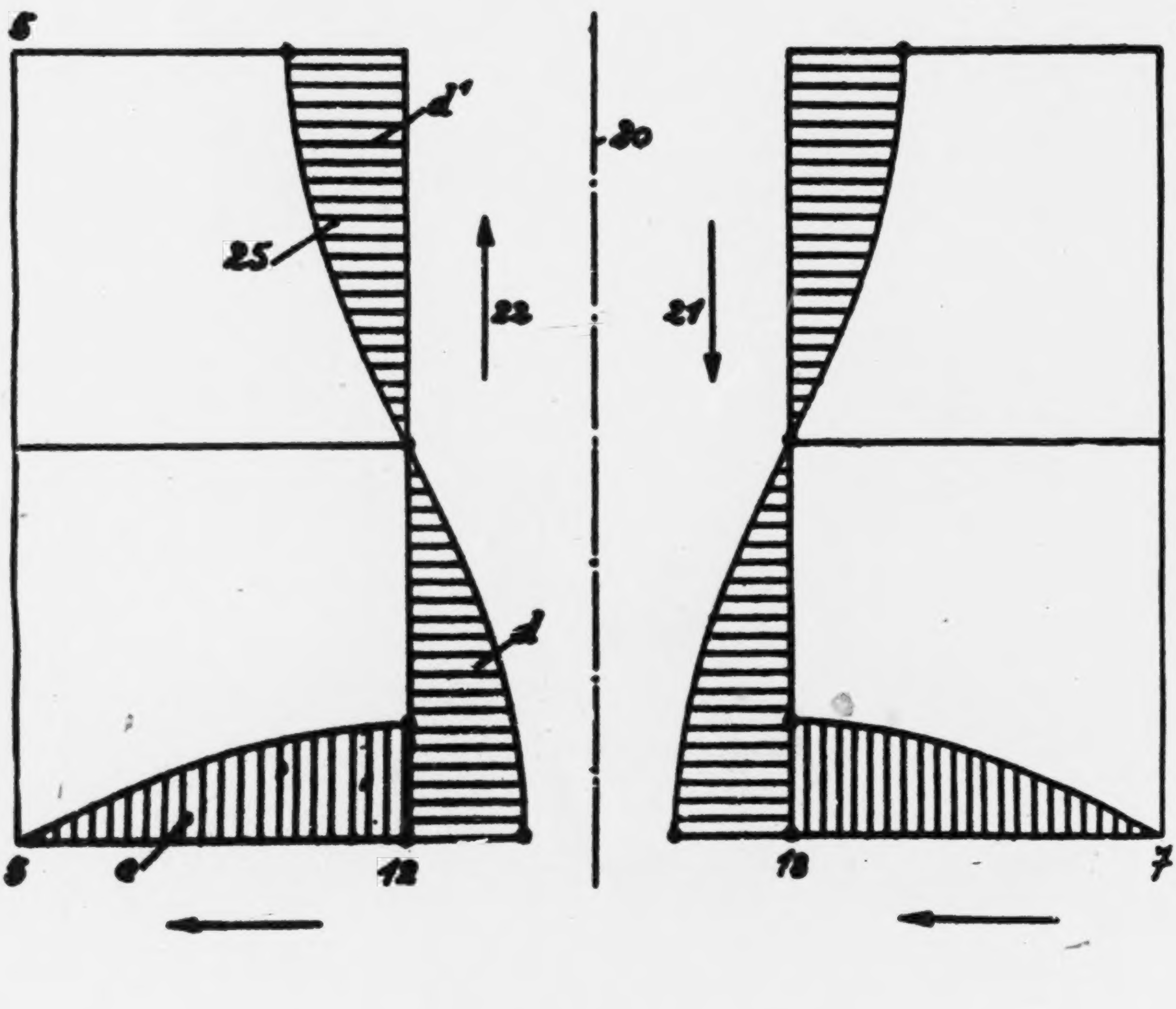
Fig.4



233,346 COMPLETE SPECIFICATION

[This Drawing is a reproduction of the Original on a reduced scale]

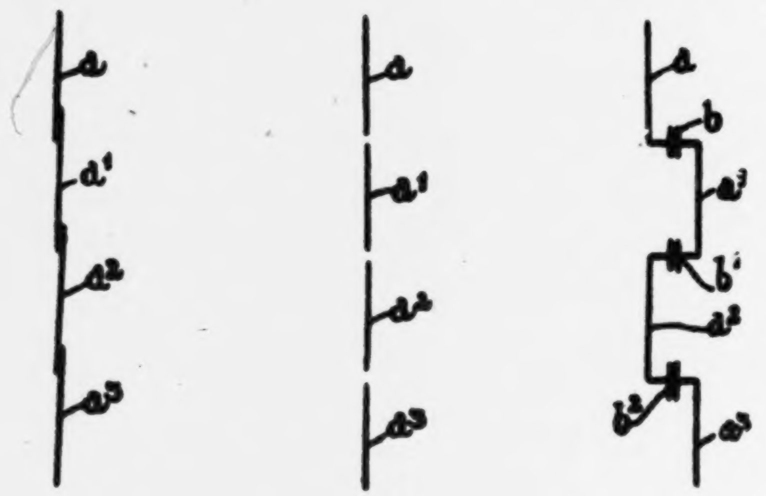
Fig. 4



233,346

4 SHEETS
SHEET 4

Fig. 5. Fig. 5a Fig. 5b



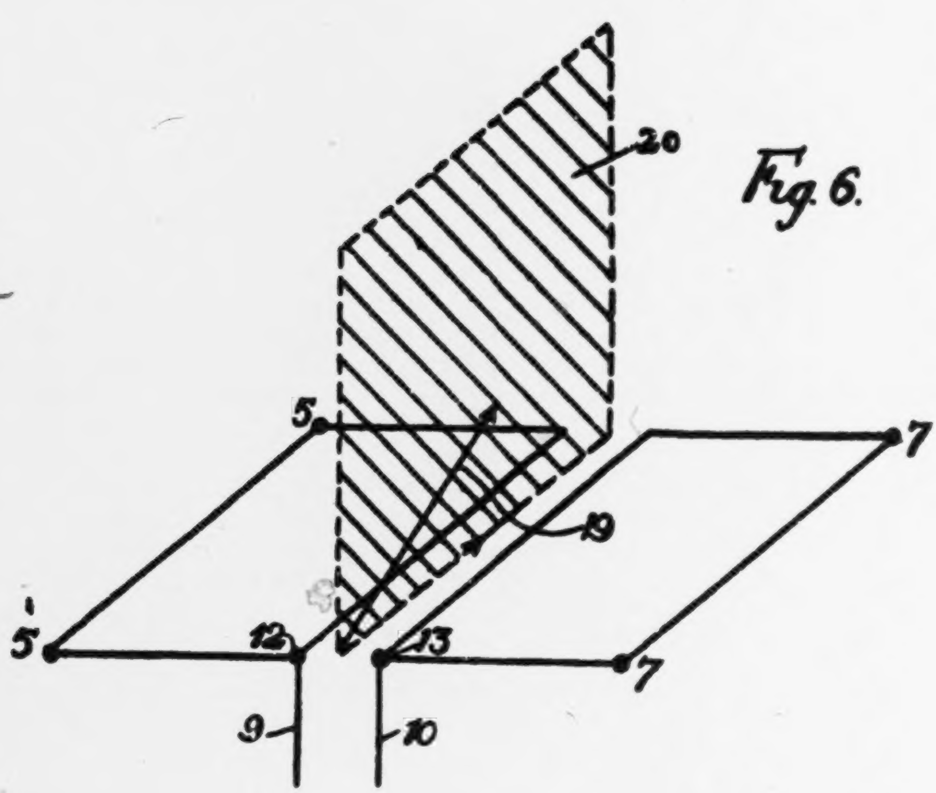


Fig. 6.

233.346 COMPLETE SPECIFICATION

Fig 7.

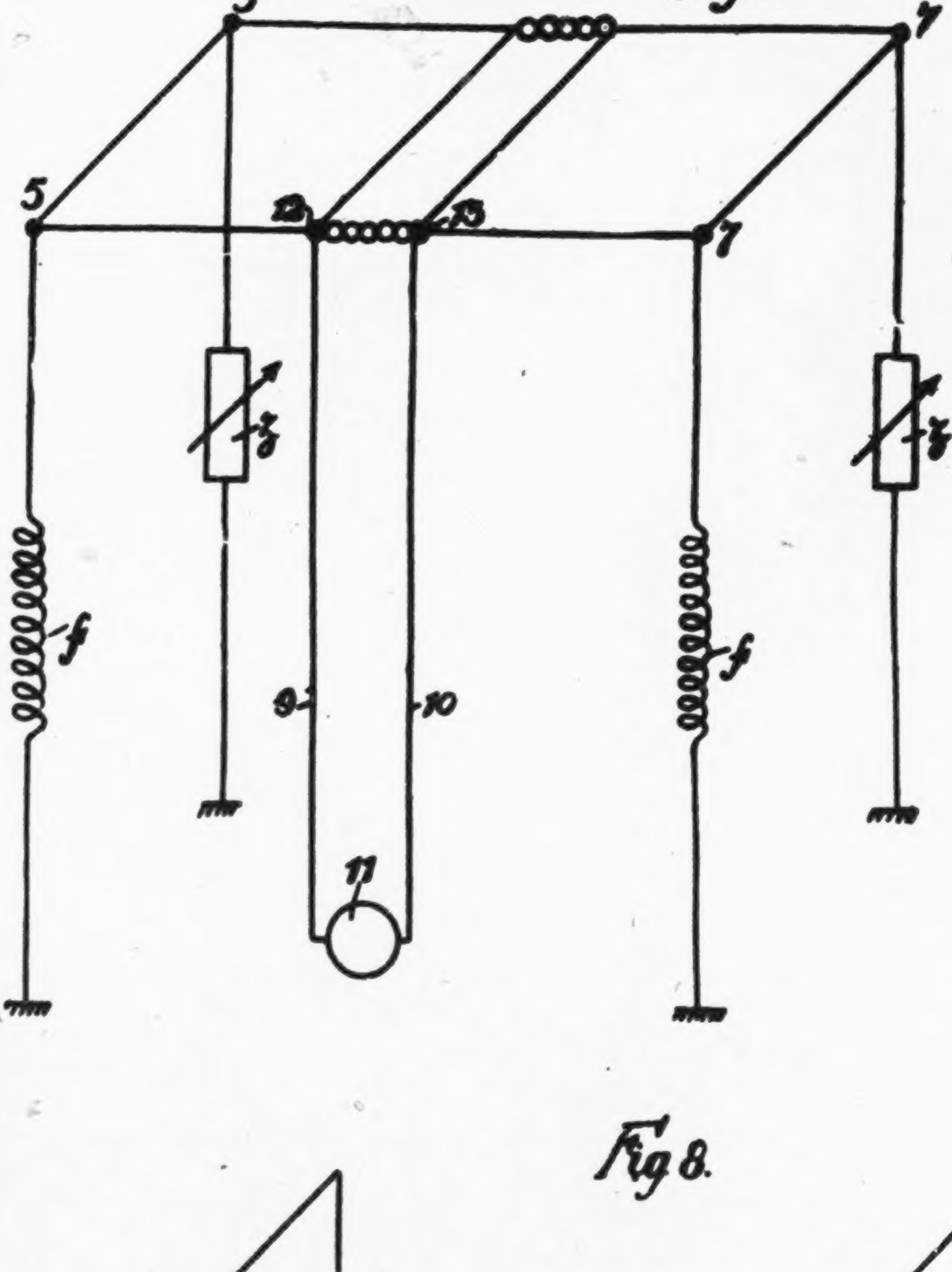
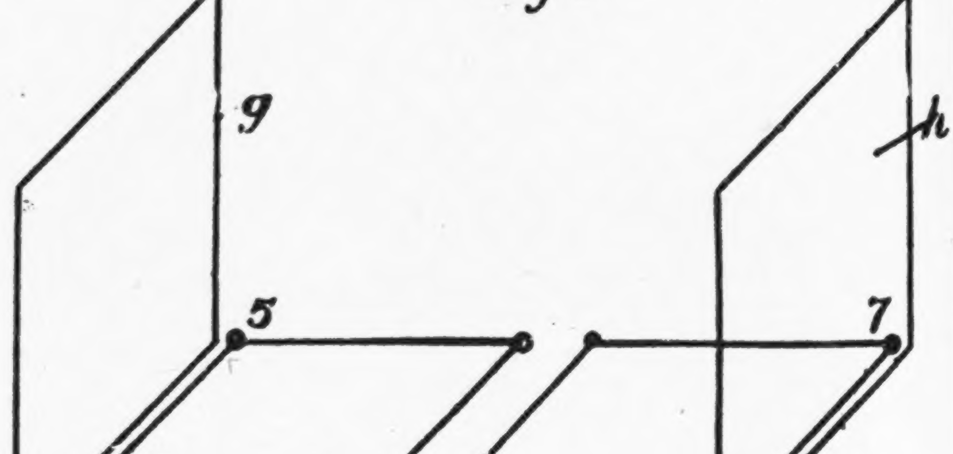


Fig 8.



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PLAINTIFF'S EXHIBIT No. 58

PATENT SPECIFICATION

Convention Date (France): April 28, 1925. **251,638**

Application Date (in United Kingdom): April 28, 1926. No. 11,211/26.

(Patent of Addition to No. 233,346: dated April 29, 1924.)

Complete Accepted: Oct. 28, 1927.

COMPLETE SPECIFICATION.

Improvements in or relating to Directive Aerials.

I, LUCIEN LEVY, of 66, rue de l'Universite, Paris, France, a citizen of the Republic of France, do hereby declare the nature of this invention and in what manner the same is to be performed, to be particularly described and ascertained in and by the following statement:—

This invention relates to improvements in or modifications of directive aerials of the kind described and claimed in my Specification No. 233,346, in which the use of radiation with a horizontal electric vector was described.

It must first be observed that instead of the arrangements indicated in the above-cited specification, it is possible to contrive different modifications which may be advantageous in many cases, particularly when it is expedient to radiate energy in a given direction.

For instance, the wires 1 and 2 in the arrangement shown in Fig. 1 of the drawing annexed to the above-named specification, instead of being parallel to one and the same direction, may be placed so as to form an angle and may, for instance, be perpendicular to each other.

It is not necessary, however, to supply the different horizontal radiating elements with voltages of opposite phase and an improvement of my invention consists in supplying said elements with voltages which are out of phase relatively to each other by any amount, which may be constant or may vary with time. Further, two rotating high-frequency oscillators of different frequencies may be superimposed on one another.

Referring to the appended drawings, which illustrate as examples, various modes of application and of realisation of the improved arrangement, object of this invention:

Fig. 1 shows an aerial composed of two branches in the horizontal plane, but inclined to one another;

Fig. 2 shows a modified arrangement of the aerial;

Fig. 3 shows a further modification.

In Fig. 1 the radiators 1, 2 are situated in the same horizontal plane and at an angle less than 180°. In Fig. 2 the radiating planes are constituted by the wires 27, 23, 24 and 28, 25, 26.

These arrangements are characterised by horizontal radiating elements, through which high frequency currents pass at a sufficient height from the ground (greater than ½ wave length), the two poles of the high frequency generator being respectively connected each to one or several radiating elements.

Fig. 3 shows an aerial with two horizontal radiating elements supplied with currents having any phase displacement.

In this arrangement, the points 29 and 30 of the element 34, 35 correspond to the points 5, 7 of the portion 1, 2 of the aerial; the points 12 and 13 of the radiating element 1, 2 are connected to the generator 11 and the points 31 and 32 of the radiating element 34, 35 are connected to the generator 33.

The generator 33 is 90° out of phase with regard to generator 11. These two generators have been shown as being separate for clearness, but usually they would not be separate and two circuits of a system comprising one or several thermionic tubes may actually be substituted.

When both radiating elements are perpendicular to each other and when the voltages at which they are supplied are

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of the same frequency and their phase is displaced by 90°, a horizontal electric field rotating at high frequency and with very peculiar radiating effects is produced. Said field is a circularly polarised field, its rotary frequency is equal to the frequency F of the currents passing through the radiators. The directive effect of the waves disappears.

When, however, currents of the same frequency F, but out of phase by less than 90°, pass through the radiators, an elliptically polarised field is produced.

Lastly, when two currents in mutually inclined conductors of equal amplitude and of frequencies F_1 and F_2, respectively, pass through each radiator—the two currents of the second radiator respectively differing in phase by ± 90° from the pair of currents in the first radiator, the superimposition of two rotating fields of different frequencies is produced. If one puts down $\omega 1 = 2\pi$ F_1 and $\omega 2 = 2\pi$ F_2, the components in a given horizontal direction, the whole field H is equal to H. sin $\omega_1 t$ + H. sin $\omega_2 t$, consequently H = 2 sin $\frac{\omega 1 + \omega 2}{2} t$ cos $\frac{\omega 1 - \omega 2}{2} t$, and everything takes place as if the field of frequency $\frac{\omega 1 + \omega 2}{2}$ rotated at a speed $\frac{\omega 1 - \omega 2}{2} t$ in a horizontal plane. The result is the same for the radiated field, and a field rotating at the speed of $\frac{\omega 1 - \omega 2}{2}$, which is slower than the emitting pulsation 2π F. is produced in any point in space. The fields may be rotated at a speed of approximately 1000 or even 10,000 turns per second.

As will be seen, the system which has just been described allows of producing at the receiving station a horizontal oscillating electric field whose plane of polarisation rotates at a speed comprised between zero and 2π F.

This result is of great importance as it allows of a real synchronising between the sending and the receiving stations and an absolutely certain suppression of parasites which do not appear in any way in such a form of rotary fields.

The first essays made with horizontal waves give considerable ranges, even by day, and upon wave lengths of the order of 80 m. with the disappearance of the fading effect. Radiation takes place apparently not only in the expected direction but also perpendicularly, and that may be explained by the effects of circular polarisation referred to above.

It must be noted that the generators feeding the horizontal aerials are supposed to be placed on the ground and to be connected to the radiating part of the aerial by a double wire line, this arrangement being evidently necessary when it is desirable to maintain the generator upon the ground, the lowest height of the aerial above the ground being given. If, however, the generator may be supported on a level with the aerial, the feeding line is omitted.

Having now particularly described and ascertained the nature of my said invention and in what manner the same is to be performed, I declare that what I claim is:—

1. A directive aerial as claimed in Specification No. 233,346, comprising two radiating elements situated in a horizontal plane, at a height above the ground, and connected to a generator which can be either level with the aerial or located upon the ground, and connected to the aerial by means of a double wire line, characterised in that the two said radiating elements are rectilinear and mutually inclined.

2. A directive aerial as claimed in Specification No. 233,346, further characterised in that the radiating elements are supplied with voltages out of phase relatively to one another, for instance, by 90°.

3. A directive aerial as claimed in the preceding claims, adapted to generate radiation polarised in a rotating plane.

4. The directive aerials, substantially as described and as illustrated in the accompanying drawings.

5. The method of electromagnetic transmission at a distance, substantially as described and illustrated in the accompanying drawings.

Dated this 27th day of April, 1926.

MEWBURN, ELLIS & Co.,
70—72, Chancery Lane, London, W.C. 2.
Chartered Patent Agents.

Redhill: Printed for His Majesty's Stationery Office, by Love & Malcomson, Ltd.—1927.

251,638 COMPLETE SPECIFICATION

SHEET 1

(This Drawing is a reproduction of the Original on a reduced scale)

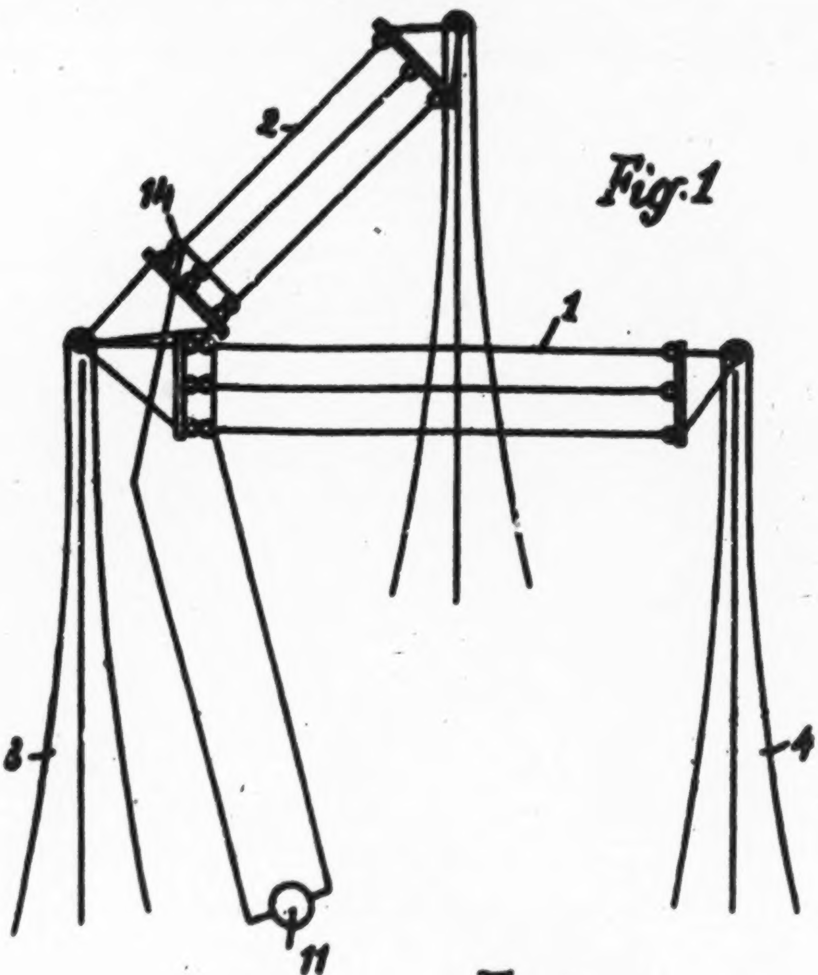
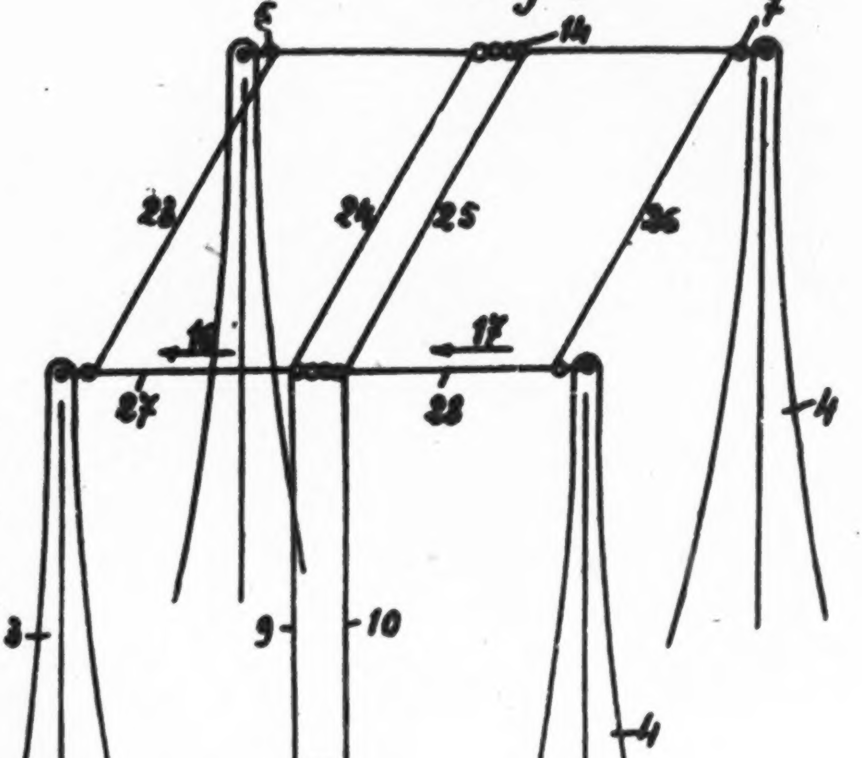


Fig. 1

Fig. 2



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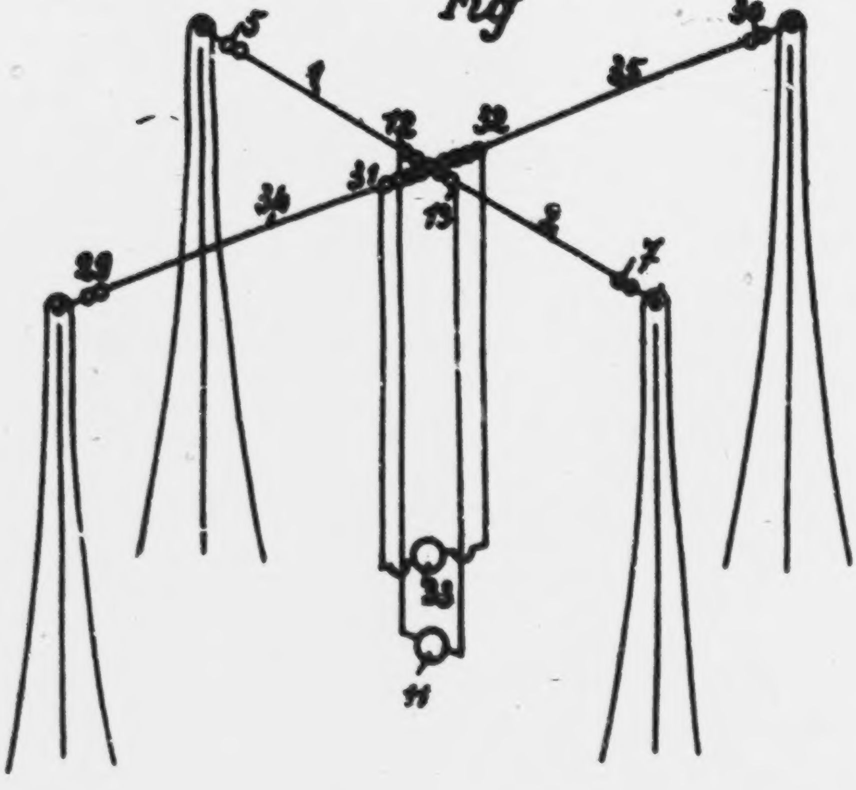
3 SHEETS
SHEET 3

Fig 3



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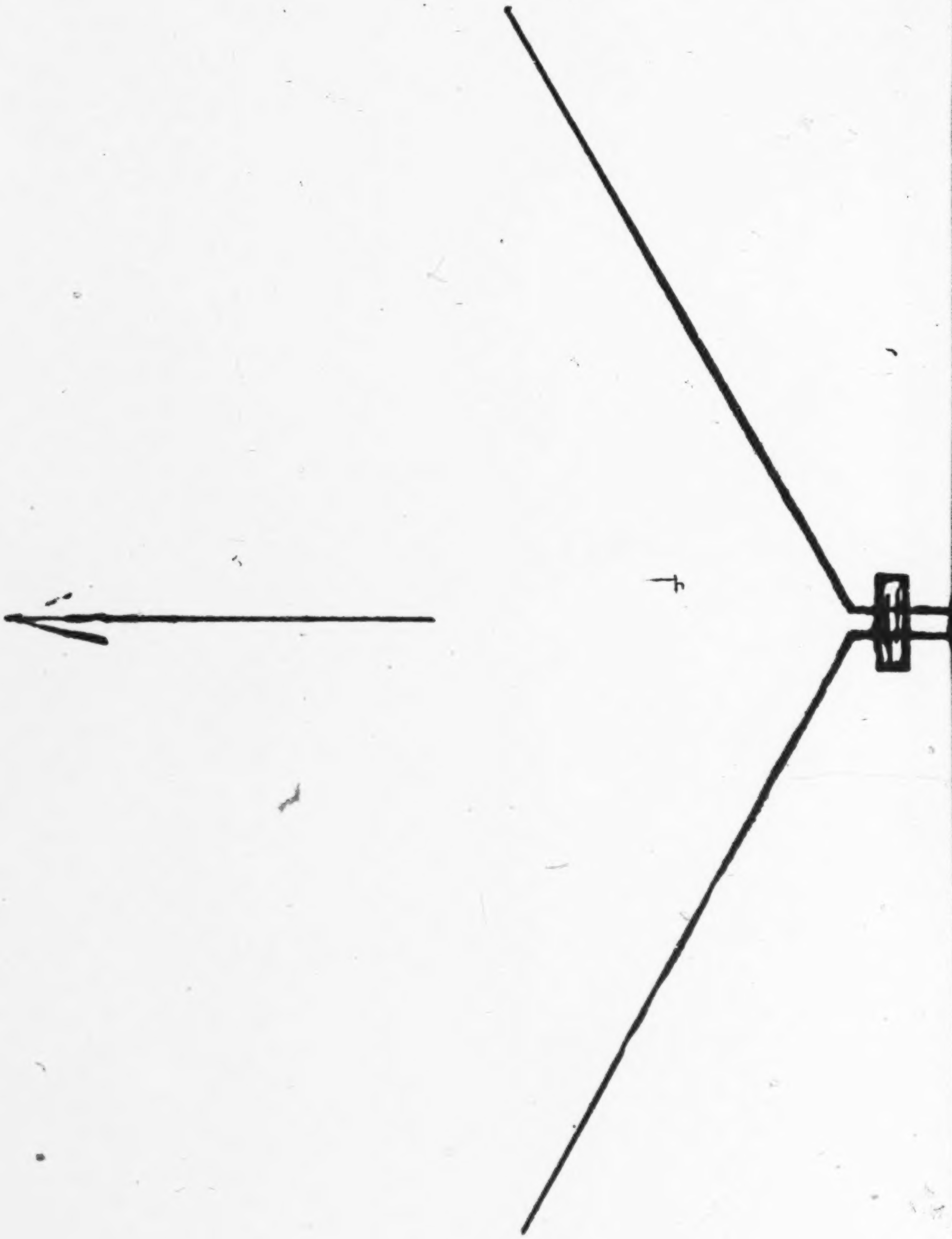
DEFENDANT'S EXHIBIT A

A/2

DEFENDANT'S EXHIBIT F



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DEFENDANT'S EXHIBIT G
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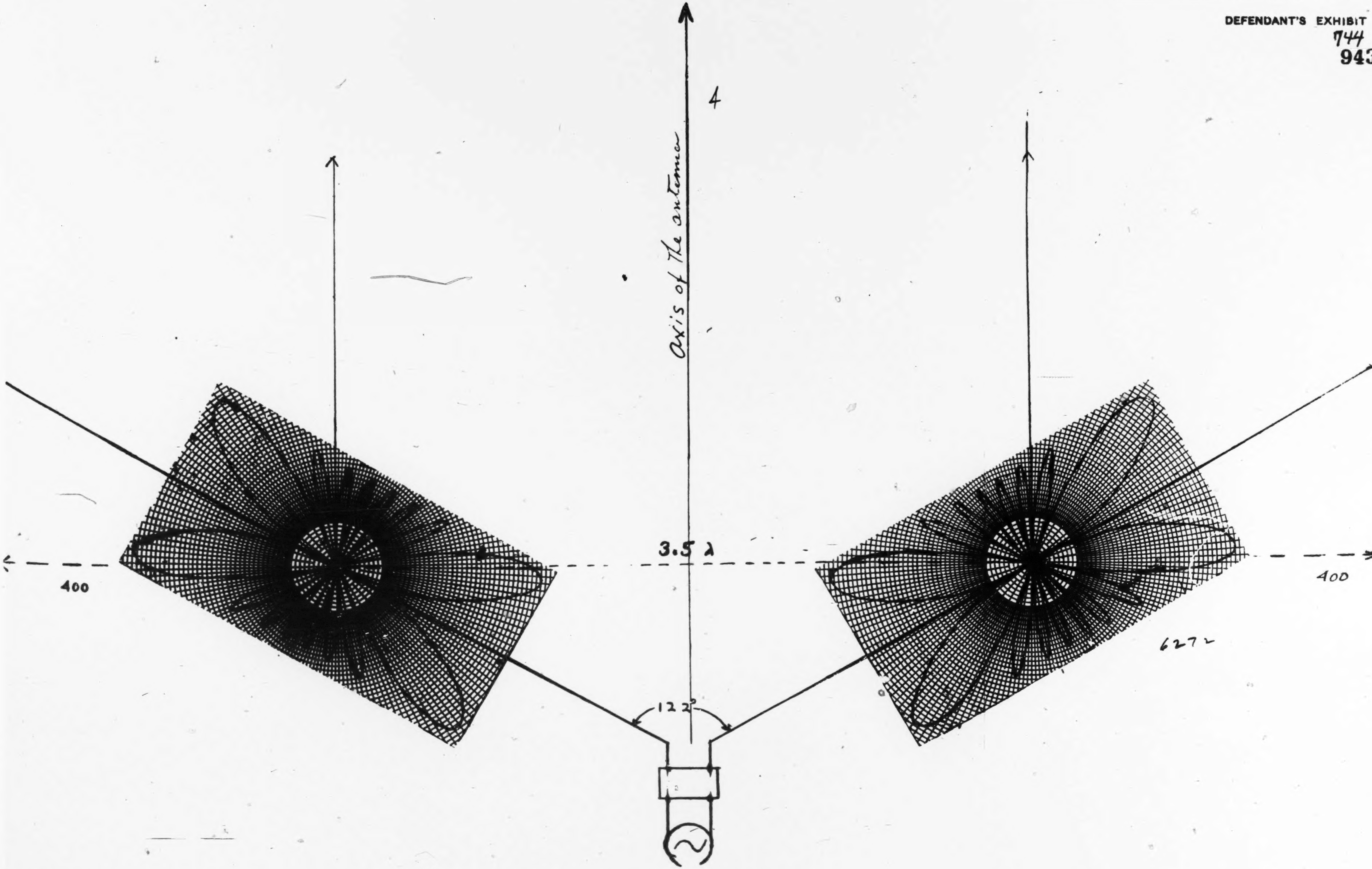


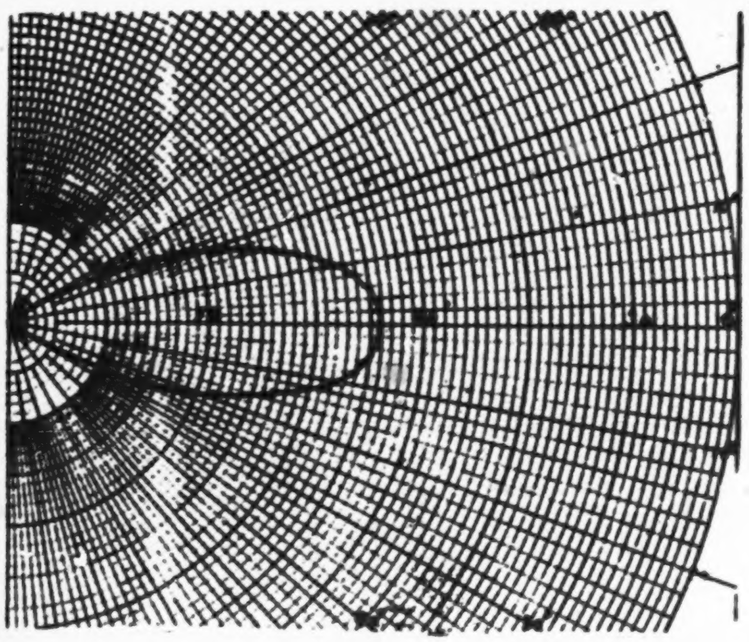
DEFENDANT'S EXHIBIT 944

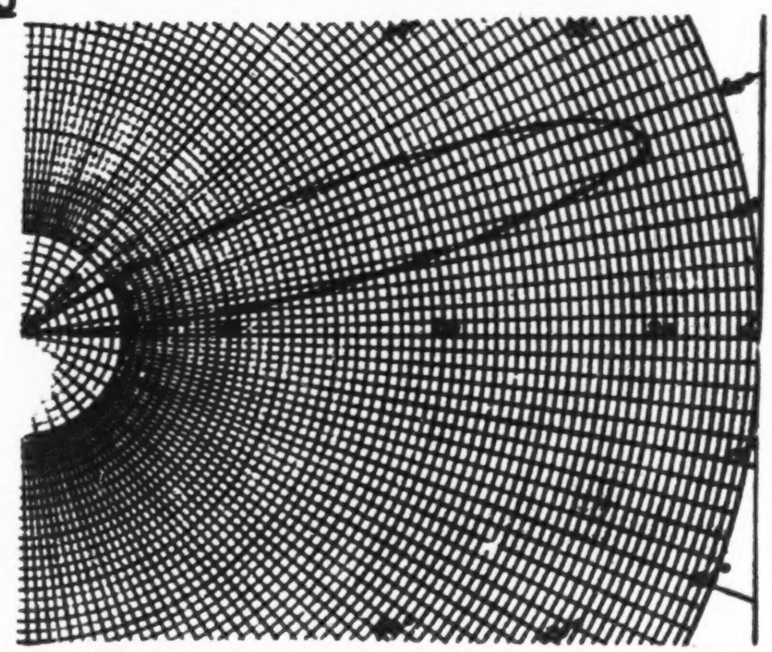
RADIATION PATTERN OF DEFENDANT'S ANTENNA NO 8

WHAT IT WOULD BE IN A DIRECTION ALONG THE BISECTOR OF THE ANGLE OF THE CONDUCTORS

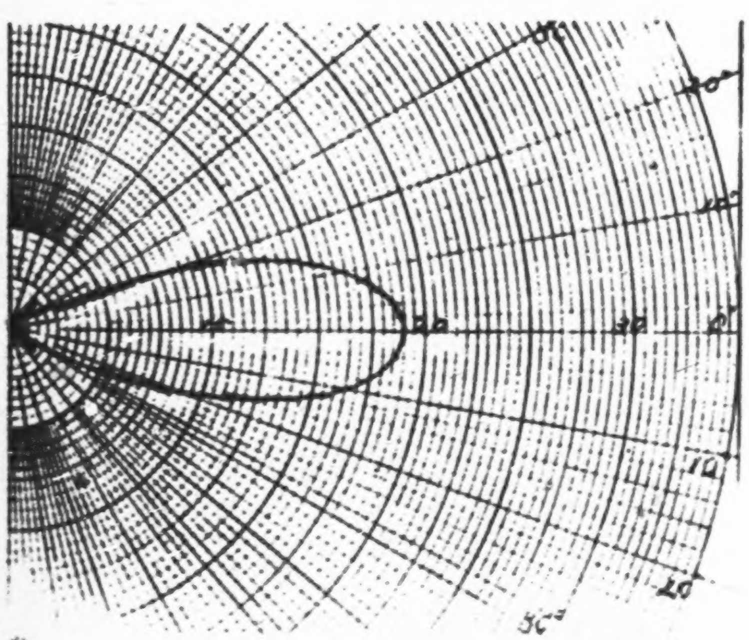
WHAT IT ACTUALLY IS

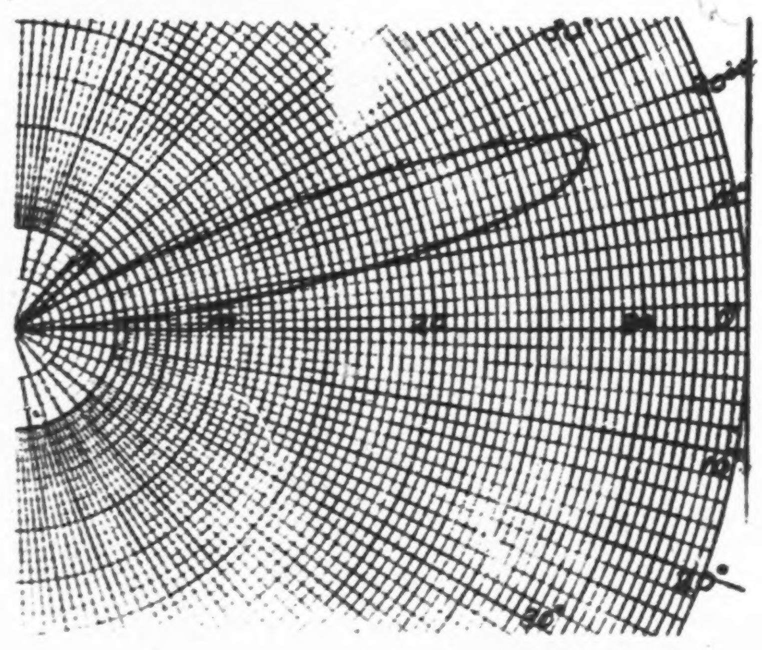
Angle of V 45°





WHAT THE CORRESPONDING PATTERNS WOULD BE IF THE ANGLE OF V WERE 50°





DEFENDANT'S EXHIBIT T

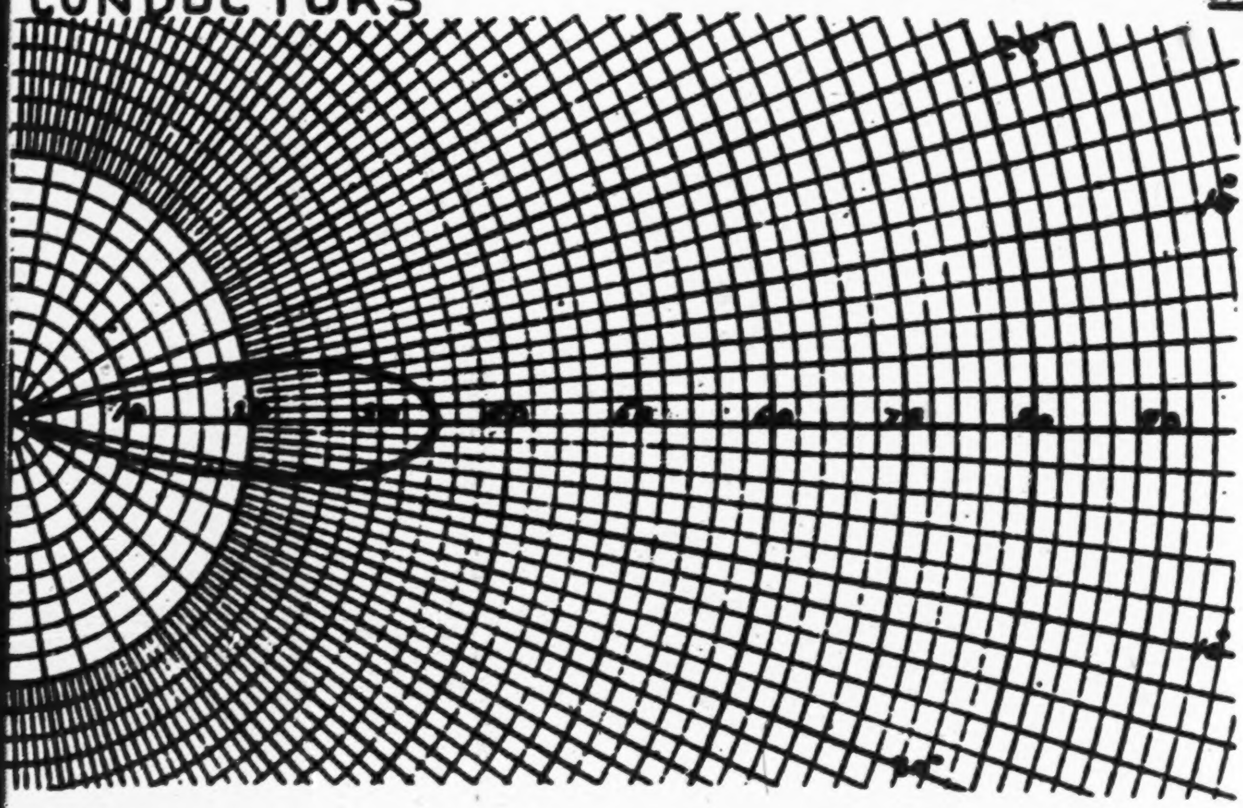
RADIATION PATTERN OF DEFENDANT'S ANTENNA NO. 2

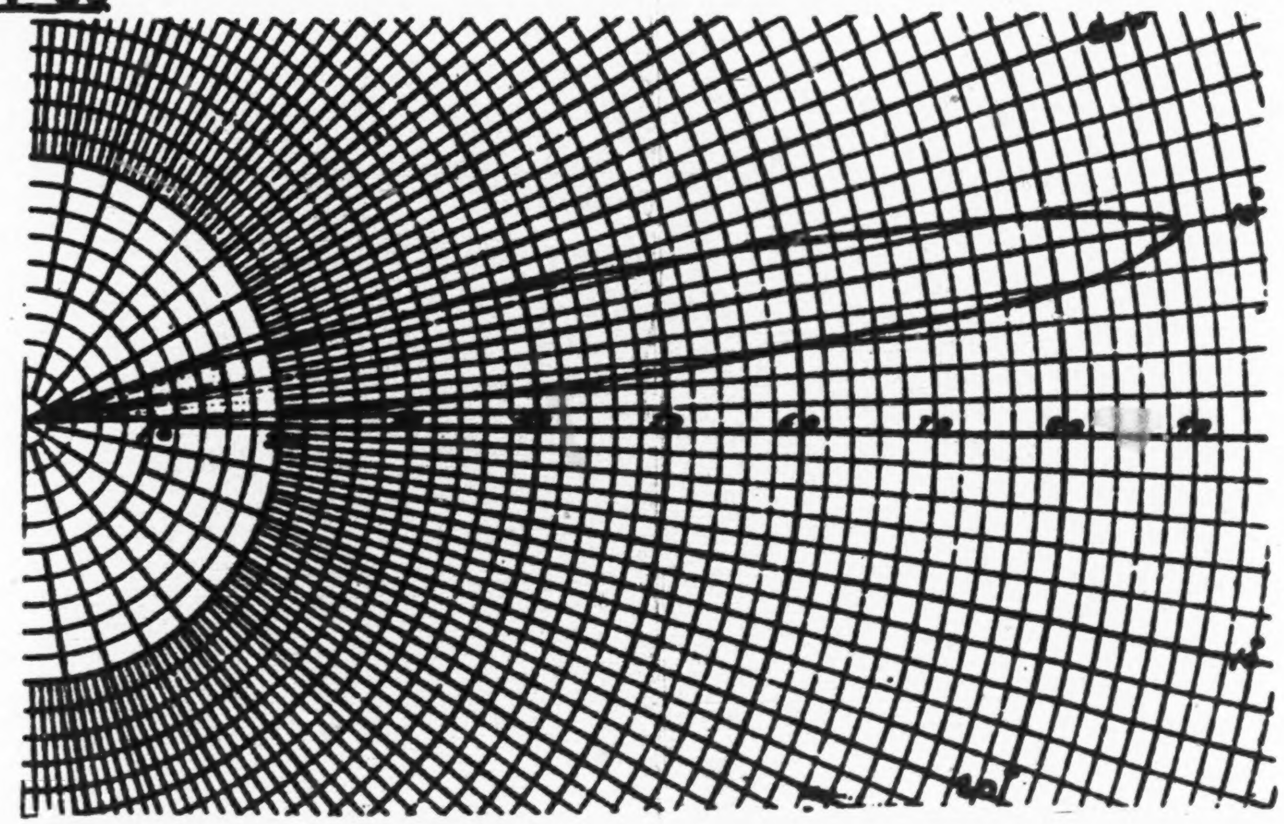
945

WHAT IT WOULD BE IN A DIRECTION ALONG THE BISECTOR OF THE ANGLE OF THE CONDUCTORS

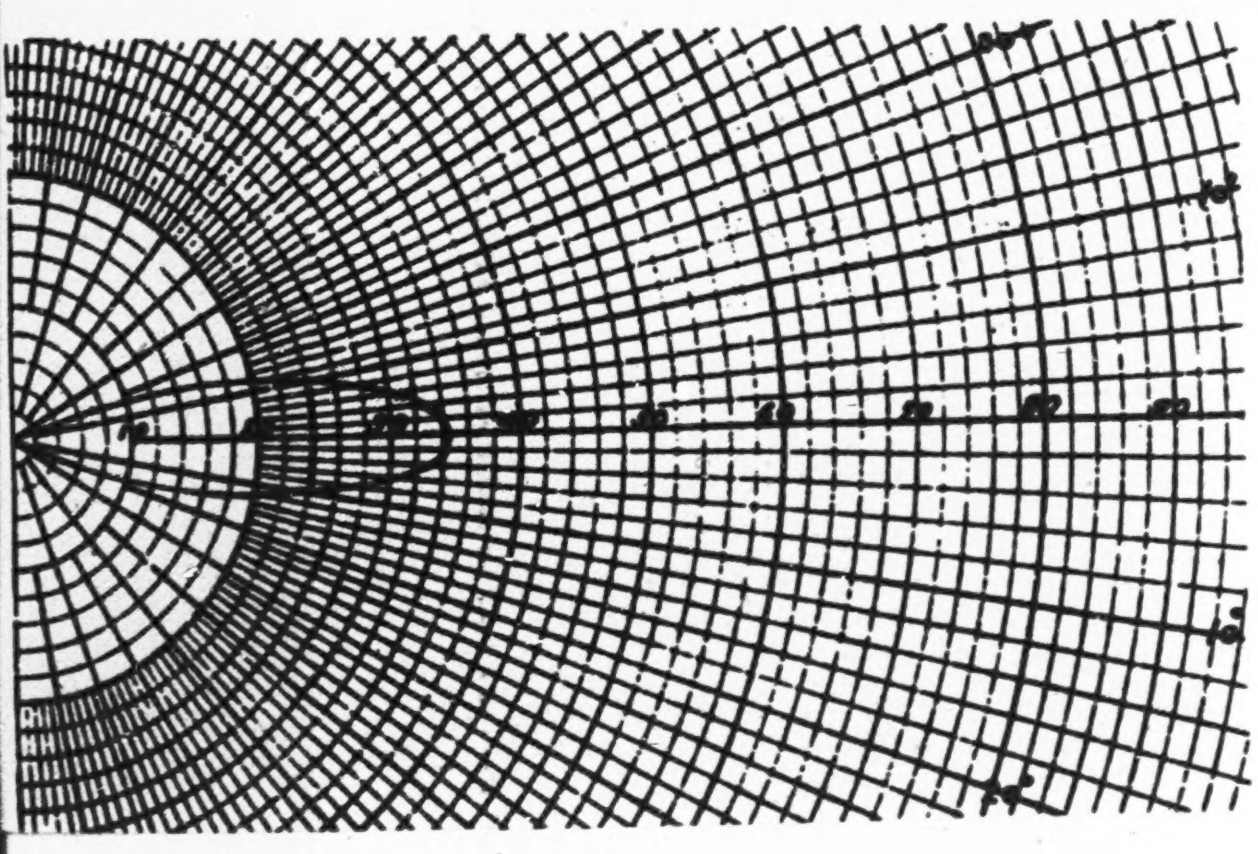
Angle of V 35°

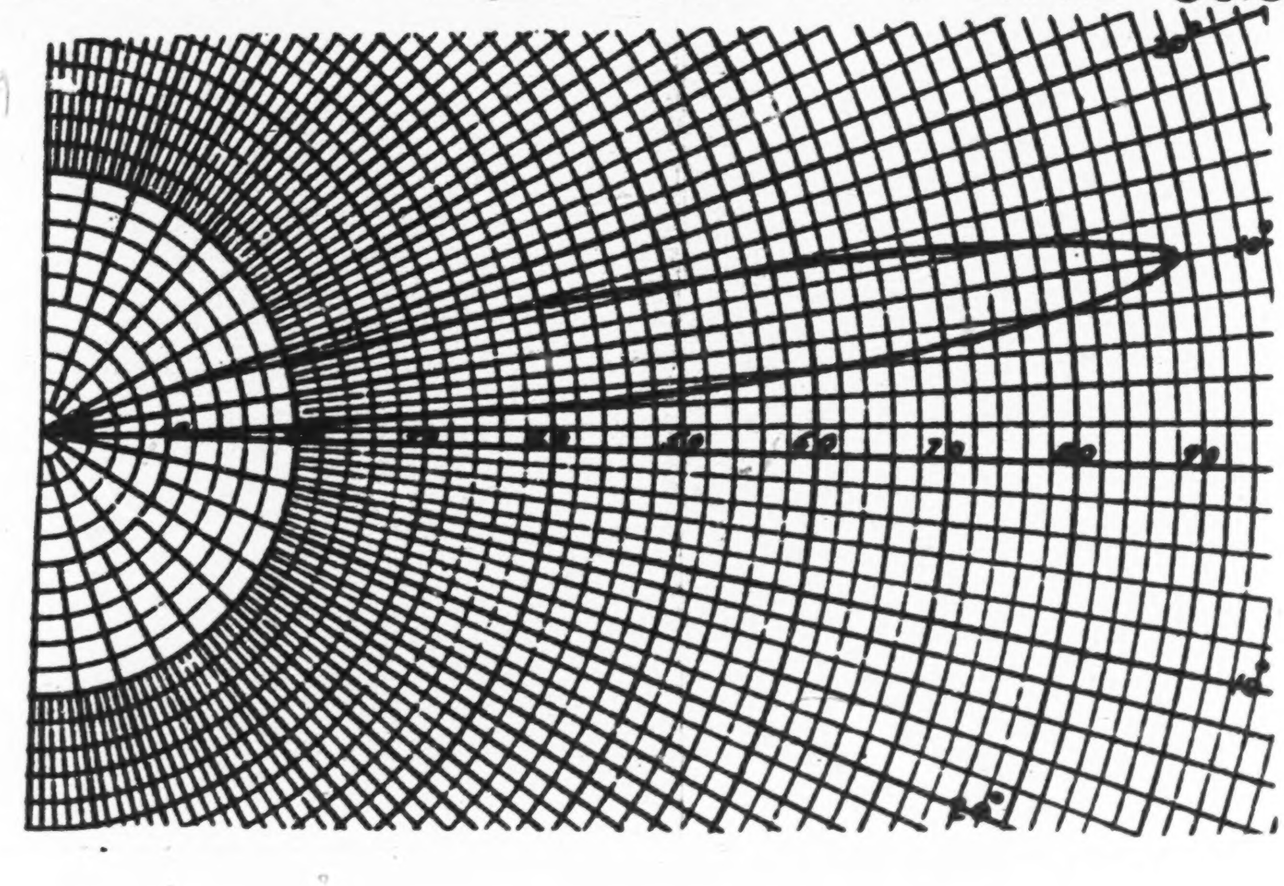
WHAT IT ACTUALLY IS





WHAT THE CORRESPONDING PATTERNS WOULD BE IF THE ANGLE OF V WERE 35.6°





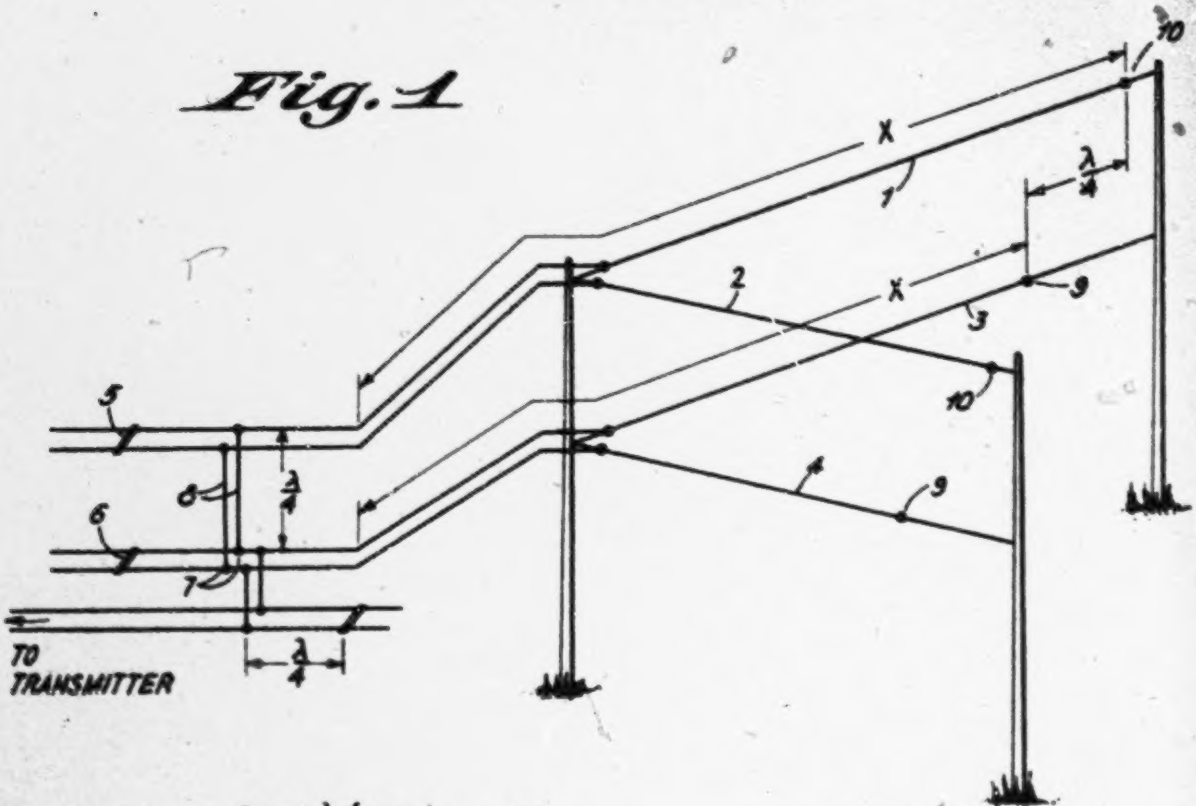
[fols. 946-959] DEFENDANT'S EXHIBIT U

Jan. 7, 1936. P. S. CARTER 2,027,020

DIRECTIONAL ANTENNA

Filed Sept. 15, 1932 4 Sheets-Sheet 1

Fig. 1



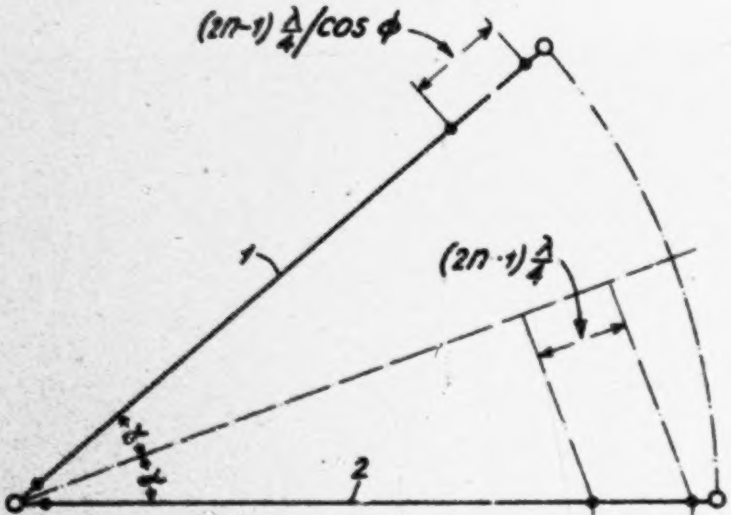


Fig. 2a

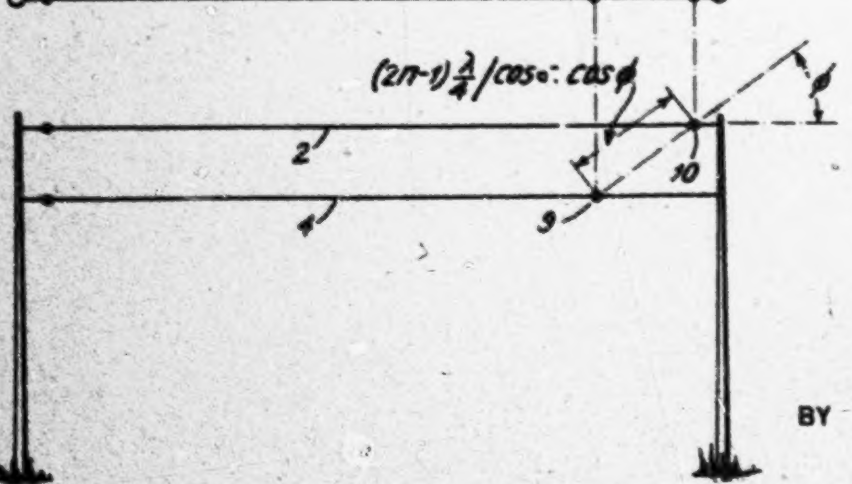


Fig. 2b

INVENTOR
P. S. CARTER
BY H. S. Grover
ATTORNEY

750

Jan. 7, 1936.

P. S. CARTER

DIRECTIONAL ANTENNA

Filed Sept. 15, 1932

2,027,020

4 Sheets-Sheet 2

Fig. 3

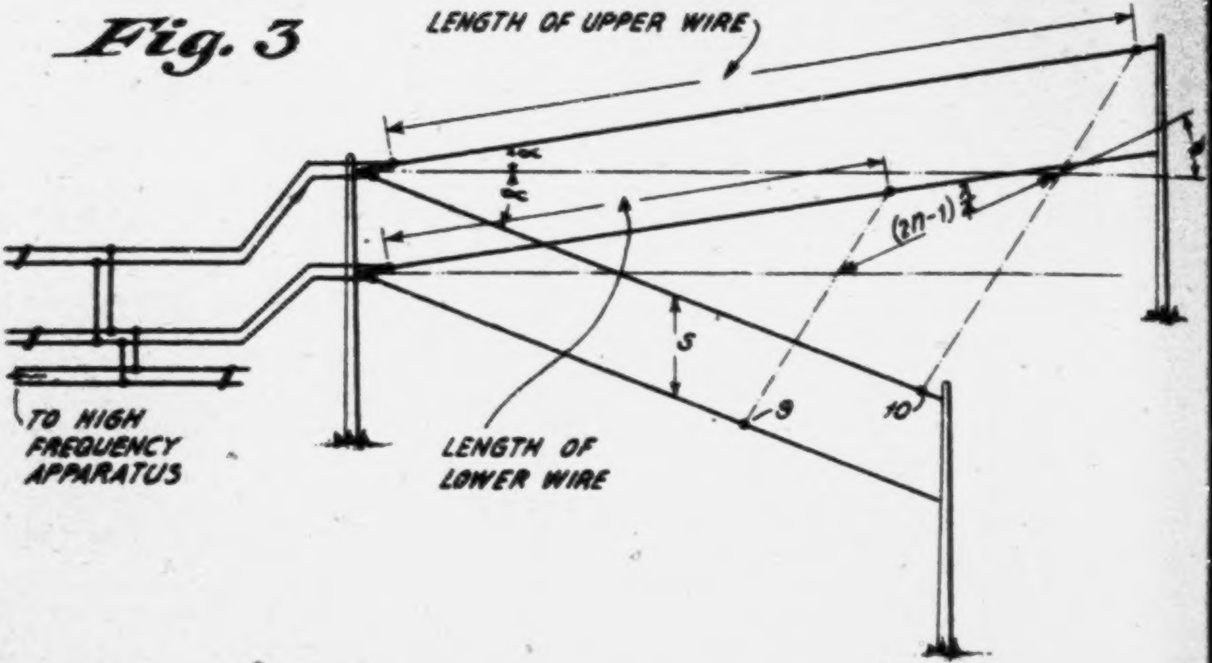
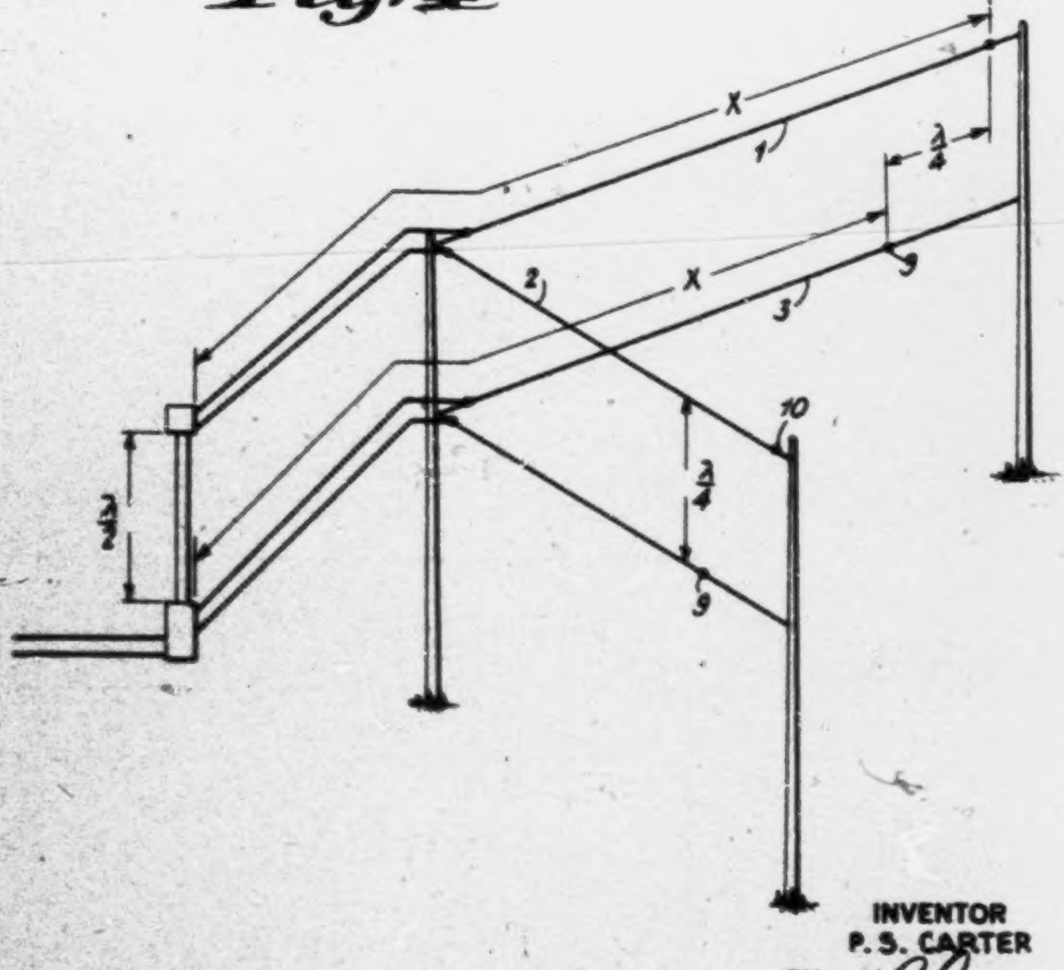


Fig. 4



INVENTOR
P. S. CARTER
BY H. S. Grover
ATTORNEY

752

Jan. 7, 1936.

P. S. CARTER

DIRECTIONAL ANTENNA

Filed Sept. 15, 1932

2,027,020

4 Sheets-Sheet 3

Fig. 5

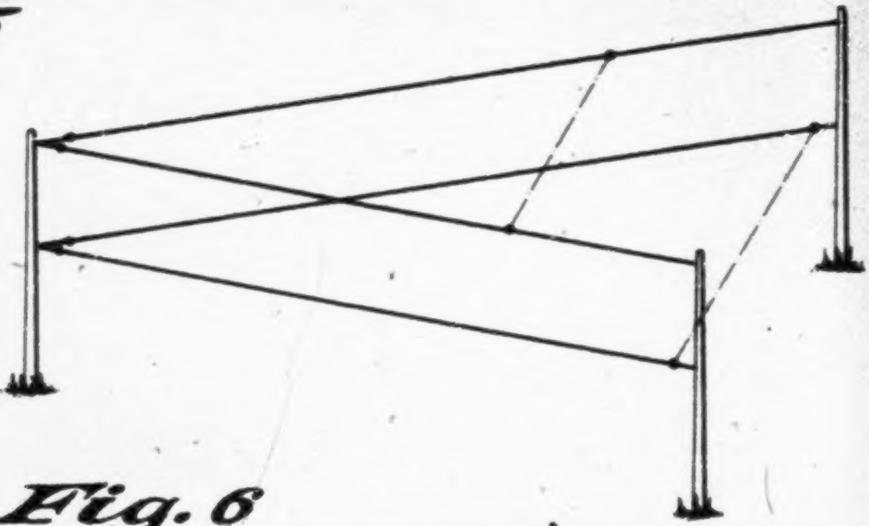


Fig. 6

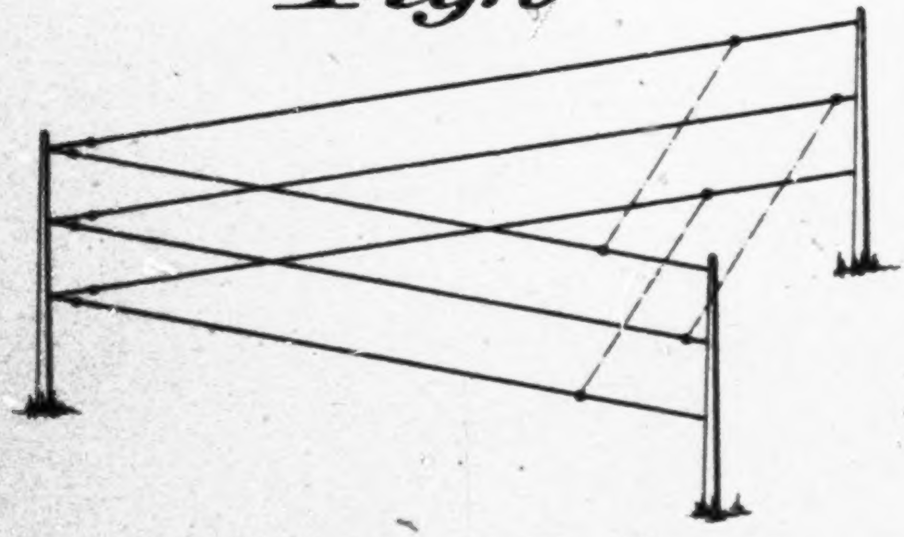
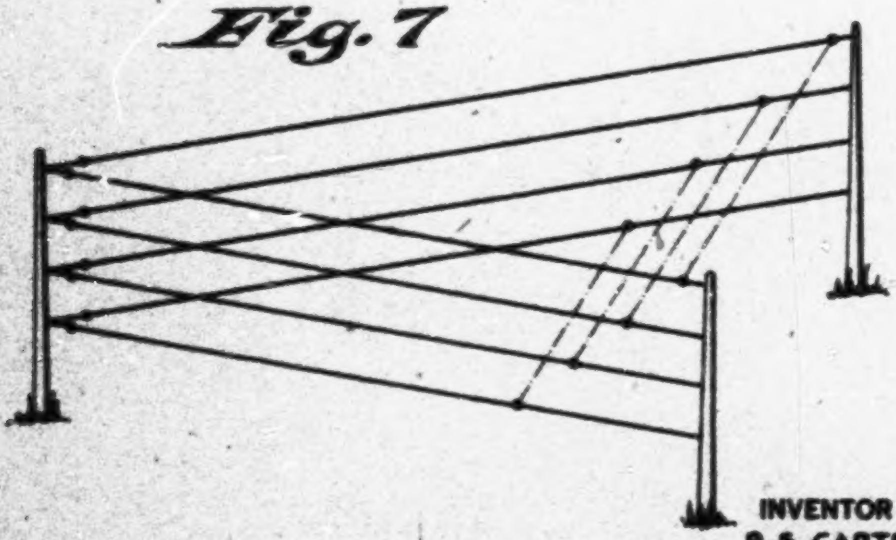


Fig. 7



INVENTOR
P. S. CARTER
BY H. S. Grover
ATTORNEY

754

Jan. 7, 1936. P. S. CARTER 2,027,020

DIRECTIONAL ANTENNA

Filed Sept. 15, 1932 4 Sheets-Sheet 4

Fig. 8

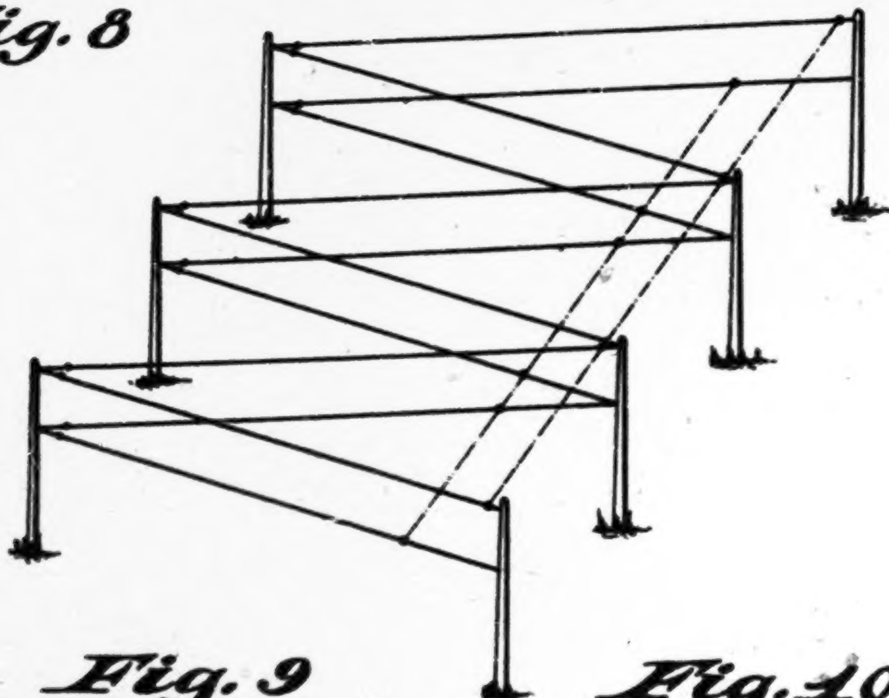


Fig. 9

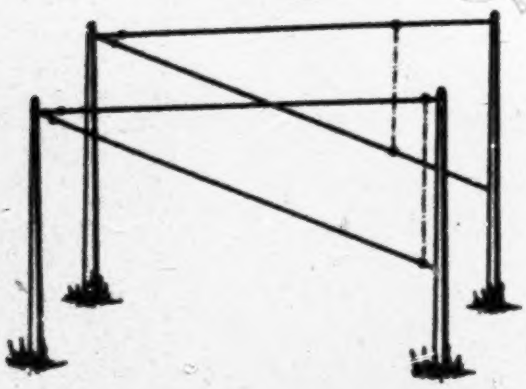


Fig. 10

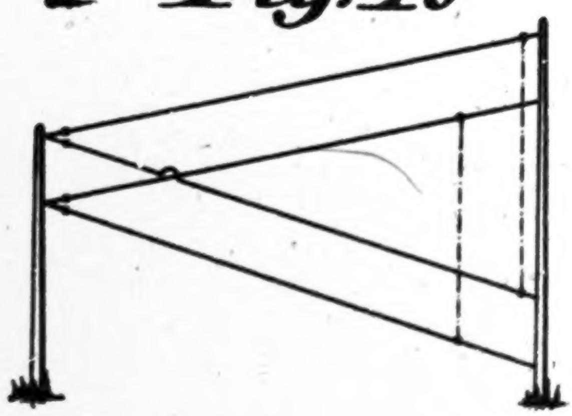
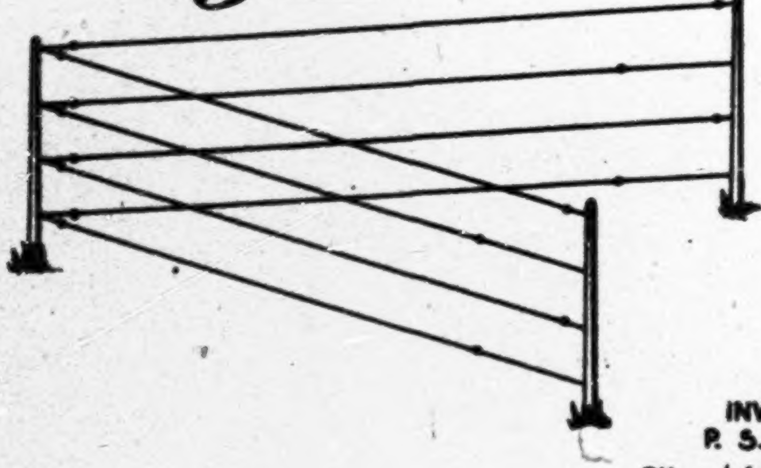


Fig. 11



INVENTOR
P. S. CARTER
BY H. G. Grover
ATTORNEY

Patented Jan. 7, 1936

2,027,020

UNITED STATES PATENT OFFICE

2,027,020

DIRECTIONAL ANTENNA

Philip S. Carter, Port Jefferson, N. Y., assignor to Radio Corporation of America, a corporation of Delaware

Application September 15, 1932, Serial No. 633,328

25 Claims. (Cl. 250—11)

This invention relates to antenna systems and more particularly to directive antenna systems.

In my United States Patent No. 1,974,387, granted September 18, 1934, there is described a V type antenna arrangement which is adapted to radiate energy directively. This arrangement comprises a pair of linear conductors which are long relative to the length of the communication wave and disposed at an angle in such a manner that when energized radiation occurs principally along the bisector of the angle. Such a V type antenna, it has been found, has a bi-directional characteristic radiating equally well in two directions—namely, toward the diverging ends of the conductors, and toward the converging ends of the conductors.

Heretofore, in order to obtain a unidirectional characteristic it has been the practice to place a similar parallel pair of wires arranged in the same V formation mentioned, an odd number of quarter wave lengths away from the antenna proper in a direction along the bisector of the angle formed by the wires. This second pair of wires is then left unenergized, or energized in proper quarter phase relation such that for one direction radiation cancellation occurs whereas in the other direction there is a strengthening of the propagated electromagnetic waves.

A disadvantage inherent in the system above referred to is the necessity for providing separate supporting structures for the second set of V type conductors in order to obtain the unidirectional antenna effect. The present invention overcomes this disadvantage and enables uni-directional radiation of electromagnetic energy without the necessity for the second set of supporting structures. Consequently, there is obtained, in accordance with the present invention, a system which is simplified in character and less expensive to construct and to maintain. As an illustration: Heretofore a single section V type uni-directional antenna system has required six supporting structures; the present invention has reduced this number to only three.

Essentially, the present invention comprises a uni-directional radiating system wherein two V formations of linear conductors, which are long relative to the length of the communication wave, are placed one above the other and energized in such a manner that the currents in the two V's are in phase quadrature relation with respect to each other. The radiated wave leaving the lower wires is arranged to be in leading phase with respect to that leaving the upper wire by a phase angle equivalent to the spacing along the line of the desired maximum radiation, thus adding perfectly to the radiated wave leaving the upper wire. In the reverse direction, the two waves are arranged to cancel out because of a desired time and space relation. In order to obtain correct space relation and reflector action, the wires of the lower V are shortened by a desired amount.

The invention is described more in detail in the following description, which is accompanied by drawings, wherein

Figure 1 illustrates a V type antenna system embodying the principles of the present invention; and

Figure 2a illustrates, in part, a plan view of the system of Figure 1, and Figure 2b, in part, a side view of the system of Figure 1, both parts being favorably arranged for a discussion of the principles involved in the present invention.

Figure 3 illustrates an arrangement differing from that of Figure 1 in that this arrangement causes the radiation from the upper and lower V's to add best at an angle of θ degrees to the horizon.

Figure 4 shows a system in accordance with the present invention wherein the spacing between the upper and lower wires is made one quarter wave length in order to obtain simplicity in phasing.

Figure 5 shows an arrangement similar to that of Figures 1 and 2 except that the upper wires are made shorter than the lower.

Figure 6 illustrates a system of three V's, one above the other, in which the lower and upper units are made shorter and fed in even quadrature phase with respect to the center unit.

Figure 7 illustrates a system of four V's, one above the other, in which each successive V is shorter than the one above.

Figure 8 illustrates a broadside system in accordance with the present invention, utilizing three sections.

Figure 9 illustrates an arrangement in which both of the V's lie in vertical planes and in which one of the two V's is made shorter than the other.

Figure 10 shows an arrangement wherein two V's lie in the same vertical plane and are carried by the same structures.

Figure 11 shows an arrangement of four V's lying in horizontal planes, one above the other, and made alternately long and short, the shorter V's being fed in quarter phase relation with respect to the longer V's.

Referring to Figure 1, there is shown an antenna system adapted for uni-directional radiation of electromagnetic energy comprising an upper pair of conductors 1 and 2, which are made long relative to the length of the communication wave and disposed in a horizontal plane in V formation at an angle in such manner that radiation occurs principally along the bisector of the angle. This angle depends upon the length of the conductors and the wave length in a manner which is fully described in my United States Patent

No. 1,974,387 mentioned above. Immediately below wires 1 and 2, spaced therefrom a convenient distance and mounted on the same supporting structures, are located another pair of conductors 3 and 4, also in V formation, each of the latter being respectively parallel to conductors 1 and 2.

In order to obtain the desired directive action, the lower V, comprising wires 3 and 4, is arranged so that the currents therein are in phase quadrature with respect to the currents in the upper V. One method of accomplishing this, while at the same time enabling the matching of the impedances of the transmission lines, is shown in Figure 1 wherein adjustable connection 5 enables the tuning of upper V wires 1 and 2 and adjustable strip 6 enables the tuning of the lower V wires 3 and 4. Connections 7, 7 are also arranged to be adjustable for matching the impedances of the quarter wave length jumpers 8, 8. When properly adjusted, the correct quarter wave phase relation may thus be obtained. For proper operation, the lengths of the wires extending from the ends of the conductors to corresponding positions on the upper and lower feeder pairs of the impedance matching structure, which are indicated by x, x in the drawings, should be made equal, although it will be understood that the absolute lengths are immaterial.

So far, the effects of ground upon the resulting radiation have not been mentioned. In both theory and practice it has been found that the reflections from ground are such as to always result in zero radiation horizontally at the usual communication distances from any short wave antenna. It has also been found that radiation at angles in the neighborhood of 10° to the horizon is most effective at a distance receiver. By placing a V wire radiator at a height of one wave length above the average dry ground, maximum radiation takes place at about 10½° to the horizontal. Therefore the antenna arrangement usually preferred is one in which the radiation from the lower and upper conductors adds perfectly at an angle of about 10° to the horizon and in which the mean height is of the order of one wave length.

To eliminate difficulties in adjustment caused by large mutual impedance between units, it is preferable to have the spacing between the upper and lower conductors at least one quarter wave length.

Dimensions which might be used in a typical design are as follows:

Length of upper wire=8 wave lengths

Angle of maximum radiation=10° to the horizon

Effective spacing=1¾ wave lengths along the line inclined at 10° to the horizon in the bisecting plane.

Half angle of V=α=18.5°

Lower conductors 3 and 4 are arranged to be shorter than upper conductors 1 and 2 by an amount sufficient to result in the correct space relation for reflector action. The distance between the end of the wire on the lower V and the end of the corresponding upper wire on the upper V is made an amount such that when projected upon the line of desired maximum radiation the projection is an odd number of quarter waves. There are several ways by which this relation may be accomplished, depending upon the particular condition it is desired to fulfill.

If it is desired that maximum addition of the radiation from the two V units take place horizontally then the following equation must be satisfied

$$X \cos \alpha = (2N-1)\frac{\lambda}{4}$$

wherein X is the stagger or horizontal distance between insulators 9—10, α the half angle of the V wires, N any integral number, and λ the wave length. Such an arrangement is illustrated in Figure 2.

If it is desired that maximum addition of radiation take place at an angle θ to the horizon, and a definite spacing S between wires 2 and 4 has been given, then the relation

$$X \cos \theta \cos \alpha + S \sin \theta = (2N-1)\lambda/4$$

must be satisfied.

If a definite angle ϕ for the line d between insulators 9—10 with respect to the horizon be assigned, and it is desired that best addition take place at the angle θ, the length of the line d may then be determined from the relation

$$d \cos \theta \cos d \sin \phi \cos \alpha + d \sin \phi = (2N-1)\lambda/4$$

In Figure 3 is shown a system so designed that the projection of the line d between the insulators of the upper and lower wires upon the plane bisecting the V wires coincides with the line of desired maximum addition of radiation. This is a convenient arrangement but not necessarily better than others satisfying the relations set forth.

The projection of the line d between insulators 9 and 10 in Figure 1 upon the bisecting plane should coincide with the line of maximum radiation (10° to the horizon according to Figure 3). With the foregoing conditions the following relations obtain:

$$1.75\lambda \cos 10° = d \cos \phi \cos 18.5°$$
$$1.75\lambda \cos 10° = d \sin \phi$$

from which $\tan \phi = \tan 10° \cos 18.5°$ and $\phi = 9.5°$

$$d = 1.¾ \frac{\sin 10°}{\sin 9.5°} = 1.842\lambda$$

$$\text{spacing} = S = d \sin \phi = 0.304\lambda$$

Another arrangement which has the advantage of making possible correct phasing adjustment on the antenna structure itself is shown in Figure 4. In this arrangement the vertical spacing is made

$$(2N-1)\frac{\lambda}{4}$$

with straight connections when N is odd and reversal of connections when N is even. A typical design might be:

Length of upper radiators=8 wave lengths

Angle of maximum radiation=about 10° to the horizon

Vertical spacing=¼ wave length

Effective spacing along the line of maximum radiation at 10° to the horizon=¼ wave length

Half angle of V=17.5°

$$X = \frac{\frac{\lambda}{4} - \frac{\lambda}{4} \sin 10°}{\cos 10° \cos 17.5°} = 0.88\frac{\lambda}{4} = .22\lambda$$

Length of lower wires$=8\lambda - \chi = 7.78\lambda$

The direction of maximum radiation may be reversed by making the current in the lower V lag that in the upper, assuming, of course, that the lower V wires are the shorter.

For convenience in describing this invention

it has been assumed that the shorter wires are placed below the longer. If desired, the shorter wires may be placed above the longer wires as long as the law of projection stated is adhered to. When perfect addition of radiation is to take place at an angle θ to the horizon, the stagger distance X is then given by

$$X=\frac{(2N-1)\frac{\lambda}{4}+S\sin\theta}{\cos\theta\cos\alpha}$$

this being the same relation as given previously except for a reversal of the sign before S sin θ. Such an arrangement is shown in Figure 5.

Figure 6 shows an arrangement of three V wires wherein there are two pairs of shorter wires, one above and one below the longer V pair. This has the advantage of greater concentration of radiation vertically.

Figure 7 shows an arrangement wherein several V's are placed one above the other, each being shorter than the one above and each fed in successive quarter phase relation.

Figure 8 shows a broadside arrangement of a number of systems placed side by side in order to increase the horizontal concentration of radiation.

The invention is not limited to systems wherein the V's lie in horizontal planes. Any of the arrangements described may be rotated 90° so that the wires lie in vertical planes. The radiated wave is then polarized in a vertical plane. Figures 9 and 10 show two such arrangements.

Any of the systems described may be adjusted for maximum radiation in the direction of the converging ends of the V's rather than in the direction of the diverging ends, merely by a reversal in the polarity of the feed lines between pairs.

If desired, the systems may be used without metallic connections to the reflectors since an adjustable wire pair may readily be used for tuning with excellent results.

I claim:

1. A uni-directional antenna system comprising two pairs of diverging conductors extending substantially longitudinally in the direction of desired transmission and placed one above the other, the conductors of one pair having lengths different from those of the second pair, and means for energizing said pairs in phase quadrature relation with respect to each other.

2. A uni-directional antenna system comprising more than two pairs of diverging conductors extending substantially longitudinally in the direction of desired transmission and placed one above the other, the conductors of at least one pair having lengths different from those of another pair, and means for energizing said pairs in successive quarter phase relation.

3. A uni-directional transmitting antenna system comprising two pairs of diverging conductors placed one above the other, the conductors of one pair having lengths different from those of the second pair, and means for energizing said pairs such that the waves radiated from one of them lead in phase the waves radiated from the other pair.

4. A uni-directional transmitting antenna system comprising two pairs of diverging conductors placed one above the other, the conductors of the lower of said pairs being shorter than those of the other, and means for energizing said lower pair such that the waves radiated therefrom lead in phase the waves radiated from the upper of said pairs.

5. An antenna system comprising a plurality of pairs of diverging conductors arranged in parallel planes and placed one above the other, the conductors of one of said pairs having lengths different from those of another pair, means for energizing said pairs of conductors, and means associated with said conductors for obtaining a phase displacement in space of the waves radiated from one of said pairs with respect to the waves radiated from the other of said pairs.

6. A uni-directional antenna system comprising a pair of linear conductors angular disposed in a single plane with respect to each other, each conductor having a length which is long relative to the length of the communication wave, and another pair of angularly disposed linear conductors located below said first pair, the conductors of said second pair being shorter than the conductors of said first pair, and means for energizing said lower pair of conductors whereby the currents therein are in phase quadrature relation with respect to the currents in the upper pair.

7. A directional antenna comprising a pair of linear conductors angularly disposed with respect to each other, each substantially a plurality of half wave lengths long, means for exciting the radiators in phase opposition whereby standing waves of opposite instantaneous polarity are formed on the radiators, another pair of angularly disposed linear conductors of different length spaced away from said first pair a vertical distance, said second pair of wires being energized in such manner that currents therein are in phase quadrature relation in respect to the currents in the other pair.

8. A directional antenna comprising a pair of linear conductors angularly disposed with respect to each other, each conductor having a length which is long relative to the length of the communication wave at the operating frequency, means for producing standing waves thereon whereby radiant action of the antenna is predominantly along the direction of the bisector formed by the conductors, and means for obtaining a uni-directional effect in said antenna system comprising another pair of linear conductors angularly disposed with respect to each other and spaced away from said first pair a vertical distance substantially equal to a quarter wave length and having different lengths than the wires of said first pair.

9. A uni-directional antenna comprising a pair of linear conductors angularly disposed with respect to each other, each substantially a plurality of half wave lengths long and open ended, and means for exciting the radiators whereby radiant action of the antenna is predominantly along the direction of the bisector of the angle formed by the conductors, a second pair of linear conductors angularly disposed with respect to each other, and shorter than the conductors of said first pair, located below said first pair, said second pair of conductors being arranged to be energized such that the currents therein are in phase quadrature with respect to the currents in said first pair of conductors.

10. A system as defined in claim 9, characterized in this, that the currents in said second pair are in leading phase with respect to the currents in said first pair.

11. A system as defined in claim 9, characterized in this, that said vertical spacing between

said two pairs of conductors is substantially equal to a quarter wave length.

12. A uni-directional antenna system comprising two V shaped wire formations placed one above the other, each of said V formations comprising a pair of conductors angularly disposed with respect to each other, said wires having a length which is long relative to the length of the communication wave, the wires of one pair having lengths different from the wires of the other pair, and means for energizing the lower of said two V formations in such manner that the current therein is in phase quadrature with the current in the upper V formation.

13. A uni-directional antenna system comprising two V formations placed one above the other, each V formation comprising a pair of wires angularly disposed with respect to each other, each wire being long relative to the length of the communication wave, the wires of the lower V being shorter than the wires of the upper V, and the distance between the end of one of the wires on the lower V and the corresponding wire of the upper V being such that when projected upon the line of desired maximum radiation the projection is an odd number of quarter waves.

14. A V-type directional antenna system comprising a pair of conductors angularly disposed with respect to each other and arranged in a single plane, a second pair of conductors angularly disposed with respect to each other and parallel to said first pair of conductors and spaced therefrom a vertical distance, said second pair of wires being shorter than said first pair, means for energizing said two pairs of wires such that the currents in both pairs are in phase quadrature relation with respect to each other, the horizontal distance between the ends of the corresponding wires of the first and second pairs being equal to

$$\frac{(2n-1)\lambda/4}{\cos\alpha}$$

where n is an integer, λ is the wave length, and α the half angle of the V.

15. A uni-directional transmitting antenna system comprising two pairs of diverging conductors placed one above the other, the lower of said pairs being shorter than the other, and means for energizing said lower pair such that the waves radiated therefrom lag in phase the waves radiated from the upper of said pairs.

16. A broadside antenna arrangement comprising a plurality of pairs of diverging conductors extending substantially longitudinally in the direction of desired transmission and placed one above the other, and means for energizing said pairs in successive quarter phase relation, and additional pairs of diverging conductors placed adjacent and on one side of said first pairs and similarly arranged with respect to each other to extend in the direction of desired transmission.

17. A uni-directional antenna system comprising a plurality of pairs of diverging conductors, each pair comprising wires extending substantially longitudinally in a vertical plane in the direction of desired transmission and placed one above the other, and means for energizing said pairs in successive quarter phase relation.

18. A uni-directional antenna system comprising two pairs of diverging conductors extending substantially longitudinally in the direction of desired transmission and placed one above the other, the conductors of one pair having lengths different from those of the second pair, and means for energizing said pairs in phase quadrature relation with respect to each other.

19. A V-type directional antenna system comprising a pair of conductors angularly disposed with respect to each other and arranged in a single plane, a second pair of conductors angularly disposed with respect to each other and parallel to said first pair of conductors and spaced therefrom a vertical distance, said second pair of conductors being shorter than said first pair, means for energizing said two pairs of wires such that the currents in both pairs are in phase quadrature relation with respect to each other, the horizontal distance between the ends of the corresponding wires of the first and second pairs being equal to

$$\frac{(2n-1)\lambda/4-S\sin\theta}{\cos\theta\cos\alpha}$$

where n is an integer, γ is the wave length, α half the angle of the V, S is the spacing between the upper and the lower wires and θ is the angle of maximum radiation to the horizon.

20. A V-type directional antenna system comprising a pair of conductors angularly disposed with respect to each other and arranged in a single plane, a second pair of conductors angularly disposed with respect to each other and parallel to said first pair of conductors and spaced above said first pair a vertical distance, said second pair of conductors being shorter than said first pair, means for energizing said two pairs of conductors such that the currents in both pairs are in phase quadrature relation with respect to each other, the horizontal distance between the ends of the corresponding wires of the first and second pairs being equal to

$$\frac{(2n+1)\lambda/4+S\sin\theta}{\cos\theta\cos\alpha}$$

where n is an integer, γ is the wave length, α half the angle of the V, S is the spacing between the upper and the lower wires and θ is the angle of maximum radiation to the horizon.

21. A unidirectional antenna comprising a pair of linear conductors angularly disposed with respect to each other, each substantially a plurality of half wave lengths long and open ended, and means for exciting the radiators whereby radiant action of the antenna is predominantly along the direction of the bisector of the angle formed by the conductors, a second pair of linear conductors angularly disposed with respect to each other and shorter than the conductors of said first pair, located above said first pair, said second pair of conductors being arranged to be energized such that the currents therein are in phase quadrature with respect to the currents in said first pair of conductors.

22. A unidirectional antenna system comprising two pairs of diverging conductors, the corresponding conductors of said pairs being placed one above the other, the conductors of one pair having lengths different from those of the second pair, and means for energizing said pairs such that the waves radiated from one of them lead in phase the waves radiated from the other.

23. An antenna system in accordance with claim 22, characterized in this, that said pairs of conductors are in the same vertical plane.

24. An antenna system in accordance with claim 22, characterized in this, that each pair of conductors is in a different horizontal plane.

25. A unidirectional transmitting antenna system comprising two pairs of diverging condu-

tors placed one above the other and located in different horizontal planes, the conductors of one pair having lengths different from those of the second pair, means for energizing said pairs such that the waves radiated from one of them lead in phase the waves radiated from the other pair, and another similar arrangement of two pairs of diverging conductors arranged above said first two pairs, said last two pairs being also so energized that the waves from one of them lead in phase the waves radiated from the other.

26. A unidirectional antenna system comprising a pair of linear conductors angularly disposed with respect to each other, each conductor having a length which is long relative to the length of the communication wave, and two other pairs of angularly disposed linear conductors one placed above and the other below said first pair, the conductors of said first pair having lengths which differ from the conductors of said other two pairs, and means for energizing said upper and lower pairs in phase quadrature with respect to said first pair of conductors.

27. An antenna system in accordance with claim 26, characterized in this, that the conductors of said first pair are longer than the conductors of said other two pairs.

28. A directional antenna system comprising a pair of conductors angularly disposed with respect to each other and arranged in a single plane, a second pair of conductors also angularly disposed with respect to each other and arranged in a plane parallel to said first plane but spaced away from said first plane, the wires of said second pair being shorter than the wires of said first pair, and means for energizing said pairs such that the waves radiated from one of them lead in phase the waves radiated from the other pair.

PHILIP S. CARTER.

Certificate of Correction

Patent No. 2,027,020. January 7, 1936.

PHILIP S. CARTER

It is hereby certified that errors appear in the printed specification of the above numbered patent requiring correction as follows: Page 2, first column, line 29, beginning with the word "So" strike out all to and including "18.5°" in line 61, and insert the same after line 32, second column of same page; second column, line 24, strike out the formula and insert instead $d \cos\theta \cos\phi \cos\alpha + d \sin\phi \sin\theta = (2N-1)\lambda 4$; line 41 (last line of equation), for "cos" read *sin*; page 4, second column, lines 20 and 41, claims 19 and 20 respectively, for greek letter gamma γ read λ; and that the said Letters Patent should be read with these corrections therein that the same may conform to the record of the case in the Patent Office.

Signed and sealed this 28th day of April, A. D. 1936.

[SEAL]

LESLIE FRAZER,
Acting Commissioner of Patents.

DEFENDANT'S EXHIBIT V

TRANSLATION

ANNALEN DER PHYSIK, 1898, M. ABRAHAM

Beginning page 465, Paragraph 7, Summary and Discussion of Findings.

We set out to solve the problem of determining the natural oscillations of a Hertzian exciter by way of integrating Maxwell equations. After the fundamental equations of Maxwell's electrodynamic had been brought into a form suitable for the purpose by the introduction of general orthogonal coordinates, we investigated the dependence of the frequencies and decrements of the natural waves upon the dimensions of the exciting source as well as upon the dielectric constant of the surrounding medium. In making considerations of this kind, recourse is often had to the notion of capacity taken from electrostatics; however, since with fields varying with time the definition of this term becomes invalid, we preferred to derive directly from the basic equations the following laws:

I. The frequencies of the natural oscillations of a Hertzian exciter are proportional to the root of the dielectric constant of the surrounding medium.

II. The logarithmic decrement of the damping of radiations of a Hertz exciter is independent of the dielectric constant of the surrounding medium.

III. The frequencies of the natural oscillations of geometrically similar exciters behave relative to one another as the lengths of corresponding stretches.

IV. The natural oscillations of geometrically similar exciters have the same logarithmic decrement.

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The natural oscillations are determined by the following conditions. Throughout the entire field there hold good Maxwell's equations, at the boundary of the exciter the electric force lines terminate at right angles, and at great distance there exist only waves traveling away from the exciter.

We assumed the electromagnetic field to be symmetrical to the axis of rotation of the exciter and we determined the points of the meridian plane by the aid of a system of co-focal ellipses and hyperbolas. For a rod-shaped conductor, i.e., in the case of a very elongated ellipsoid of revolution it was feasible to find an infinite number of solutions of the fundamental equations and limiting conditions representing damped oscillations in such a way that the functions determining the electromagnetic field are represented in the form of the product of a quantity variable only along the ellipses and a quantity variable only along the hyperbolas. The half waves of these natural oscillations, in the first approximation, were equal to integral parts of the rod-length. Hence, this result is found:

V. The Maxwell theory admits of the existence of an infinitely great number of nearly harmonic overtones of the rod-shaped conductors.

Regarding the symmetry properties of the field of the natural oscillations the following may be stated:

VI. In the case of the fundamental oscillation as well as of all odd-numbered natural oscillations, in two points symmetrically situated in reference to the equatorial plane, the magnetic forces are equal. The electric charges of symmetrically located points of the conductor have opposite signs.

VII. In all even-numbered natural oscillations, in two points positioned symmetrically in reference to the equatorial plane, the magnetic forces are equal and opposite; the electrical charges of symmetrically located points of the conductor have the same sign.

What follows from this last rule is that for the even-numbered oscillations in the equatorial plane, the magnetic force disappears; in other words, advancing waves will not arise there at all. Hence, the frequencies to be observed in the symmetry planes are as 1:3:5:7, etc. Nothing is altered in this situation by guiding the waves along a wire, provided that the arrangement is symmetrical. Symmetrical conductor points will always be charged in the same manner by even-numbered oscillations, hence no potential difference prevails between such points. In other words, the existence of even-numbered oscillations is not ascertainable at all by measurements made in the symmetry plane. Now, Lamotte* has recently investigated the oscillations sent out from a Lecher wire system and a Blondlot exciter. He made observations in the plane of symmetry and he discovered that in the Lecher arrangement oscillations arose whose frequencies were almost as 1:3:5, whereas in the Blondlot scheme there occurred also almost even ratios between the frequencies. The assumption made by Lamotte and Drude** that what is concerned here are harmonics or overtones of the exciter is thus in full agreement with the above law in the case of the Lecher-wire arrangement, but not in the Blondlot scheme. Now, while our theory refers, strictly speaking, only to the rod-shaped conductor, this case nevertheless may be regarded as typical for all forms of exciter in which only proximately harmonic overtones arise. It is therefore likely that the oscillations

* - M. Lamotte, Wied. Ann., 65, pp92-105, 1898
** - l.c. p104.

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noted in the Blondlot arrangement may, in part, not be interpreted as being harmonics of the exciter circuit, but may be ascribable to interactions between the primary and the secondary lines.*

The current distribution corresponding to the natural oscillations along the conductors turns out to be very simple in the presence of vanishing radiation. The nodal points of the current are only a half-wave spaced apart from one another, also the ends of the rod must be regarded as nodes. The notion customary in wire waves which regards the oscillatory state as resulting from waves reflected at the free end of the wire with reversal of sign of the current leads to the same result. That this conception is untenable, however, will be evident when an investigation is made of the electromagnetic field at some distance from the conductor, for, as shown by theory, the nodal surfaces of the magnetic force are by no means planes, but rather:

VIII. The nodal surfaces cut the meridian planes in hyperbolic branches whose foci are located at the ends of the wire.

This immediately follows from the fact that the particular solutions corresponding to the natural oscillations are representable as the products of a function variable only along the ellipses and a function being variable only along the hyperbolas. For if the magnetic force vanishes at some points of the conducting ellipsoid, it disappears along the entire "cup" of the con-focal hyperboloid of revolution containing the point in question. Rule No. VIII furnishes an explanation for certain experiments made by Sarasin and Birkeland.**

*-See J. v. Gleitler, Wied. Ann., 57, p.412, 1896, and E. Marx, Diss. p.9 Gottingen, 1898, J. v. Gleitler, Sitzungsber. Scientific Society of Vienna, 107. IIa July, 1898.

**-I.S.& B. Compte Rendus, 117, p.618-622, 1893.

These investigators examined the field in the neighborhood of a free-ended wire with a spark resonator and they found the nodal lines to be curved, with the concave face turned towards the free end. Theory, as a matter of fact, would indicate that the nodal lines in the vicinity of the free end would approximately have the shape of parabolas whose focus coincides with the end of the wire.

The emitted waves constantly extract energy from the electromagnetic field of the exciter and thus cause damping of the oscillations. If ℓ/b is the ratio of rod-length and the radius of cross-section, and if we make

$$\mathcal{E} = \frac{1}{4.\ \log \operatorname{nat} \left(\frac{\ell}{b}\right)}$$

then, in first approximation, the values of the decrement, for the fundamental wave (n = 1) will be:

$$\sigma_1 = 9,\ 74\ \mathcal{E},$$

for the first harmonic (n = 2):

$$\sigma_2 = 6,\ 25\ \mathcal{E},$$

and for all higher orders

$$\sigma_n = \frac{9,66 + 4.\ \log \operatorname{nat} (n)}{n} \cdot \mathcal{E}.$$

Hence, it will be noted that:

III. The decrements of natural oscillations of the rod-shaped conductor constantly decrease with growing ordinal number. The time-damping on the contrary, grows with growing ordinal number.

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In other words, the harmonics decay faster than the fundamental wave, and yet the amplitudes of the harmonics decrease only after a greater number of oscillations to a definite fraction of the initial value. The damping by radiation becomes vanishingly small as the cross-sectional area of the rod diminishes.

Radiation modifies the current distribution along the conductor. In the presenceof vanishing damping, the same could be regarded as the result of a wave traveling towards the free end and a wave reflected at the latter with the same amplitude, but reversed sign of the current. The influence of the radiation upon the oscillatory state has recently been investigated by Eckström* and this author believes that the same could be taken into consideration by introducing for the reflection at the end of the wire phase loss and a reduction of amplitude. However, from our own viewpoint, and for waves along a single wire, this supposition would not appear justified. For since the function $E_n(y)$ which represents the distribution of the current along the wire disappears when $y = \pm 1$, i.e., at the wire ends, there will occur there always a node of the current. What thus follows from law No. VIII is that the extensions of the wire axis are nodal lines of the magnetic force. Hence, the oscillation energy does not radiate in an axial direction, but rather in a lateral direction. The assumption may therefore be made that the influence of radiation makes itself manifest during the progression along the wire rather than upon reflection at the free end. As a matter of fact, what has been proved is this:

* - W. Wied, Ann. 64, p317,1898

TRANSLATION -

ANNALEN DER PHYSIK - 1898, Page 435 - M. ABRAHAM

4. The Electric Oscillations Around a Linear Conductor, Treated According to the Maxwell Theory. By M. Abraham.

Page 470 -

2. If one looks upon the current distribution caused by the natural periods as composed of the superposition of a wave train traveling out toward the open end and of one reflected back from the open end, there is found progressively along the length of the conductor a continual change in the amplitudes and phases of both waves. There is complete reflection at the open end.

When the effective value is measured with a bolometer or thermocouple, then its distribution lengthwise of the conductor is expressed as a first approximation, i.e., neglecting magnitudes of the order of g^2, by $\cos^2 (\frac{1}{2}\nu\pi y)$ for the odd numbered and by $\sin^2 (\frac{1}{2}\nu\pi y)$ for the even numbered periods.

At a great distance from the antenna the ellipse x = const. and the hyperbola y = const. which are determined by the position of a point in the meridian half plane become respectively a circle of radius x and a straight line, which makes an angle ϑ = arc cos y with the axis of the antenna. We are here in the region of waves traveling away from the antenna. The radial component of the electric force vanishes in comparison with the components of the electric and magnetic force standing at right angles to the direction of propagation and which are determined by the real part of,

$$\frac{e^{i_n (x-c\cdot t)}}{x} \qquad \frac{E_n(\eta)}{\sqrt{1-\eta^2}}$$

Therefore, the variation of the intensity of radiation along a meridian is expressed by the absolute magnitude of the function, 7 39 V/7

Page Tightly Bound

$$\frac{E_n^2(y)}{1-y^2} = \frac{E_n^2(\cos\varphi)}{\sin^2\varphi}$$ which, as a first approximation

is proportional to,

$$\frac{\cos^2\left(\frac{\pi n}{2}\cdot\cos\varphi\right)}{\sin^2\varphi}$$ for the odd numbered and

is proportional to,

$$\frac{\sin^2\left(\frac{\pi n}{2}\cdot\cos\varphi\right)}{\sin^2\varphi}$$ for the even numbered

periods.

XI. If the radiations given off from the Hertzian exciter comprise oscillations of different periodicities, then the share of the various constituent natural oscillations in the aggregate radiation intensity will differ for different points of a meridian.

If, on the contrary, the distribution of the total radiation of the rod-shaped exciter along a meridian is known, our findings probably enable us to decide the question whether only the fundamental wave is sent out or whether an appreciable portion of the aggregate radiation corresponds to the harmonics.

In the second approximation, i.e., if quantities of an order E^2 are taken into consideration, a correction is necessary in the above-mentioned values of the wave-lengths and the decrements, by that a certain fraction must be added to the length of the rod in order that an integral multiple of the half-wave of the natural oscillation in question may be obtained. The said fraction was

$$5.6 \times E^2 \text{ for the fundamental wave } (n = 1)$$

$$3.9 \times E^2 \text{ for the first harmonic } (n = 2)$$

$$\frac{4.8 + 2 \log nat (n)}{n} \times E^2 \text{ for all higher harmonics.}$$

Hence, it will be noted that:

XII. The correction to be made in the length of the rod in order that an integral multiple of the half-wave may be found, steadily decreases with increase in ordinal number.

In other words, the wave-lengths of the harmonics are invariably slightly smaller than what would correspond to perfect harmony with the fundamental.

In conclusion I feel it an agreeable duty to express my gratitude to my esteemed teacher and superior Prof. M. Planck, for his friendly interest in connection with my above research work.

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Physikalische Zeitschrift,

Second Year, March 2, 1901,
Pages 329-334

Spark Telegraphy and Electrodynamics

By M. Abraham.

When Heinrich Hertz discovered the property of the electric spark of resulting in very rapid electrical oscillations, he made an attempt to decide between the various electrodynamic theories advanced at that time. His investigations convincingly confirm Maxwell's theory, in fact, they showed that electric waves travel at the speed of light into the ether, and that, as asserted by Maxwell, they differ from light waves only in that they are of a greater wave-length.

Telegraphic communication or signaling by the intermediary of Hertzian waves over relatively great distances, known as spark telegraphy, was carried into practise first by Marconi. In this connection in contrast with laboratory arrangements, a number of modifications proved expedient. At the exciter was mounted a vertical wire; from the latter, the sending wire, waves are radiated off in all directions into ether and they carry the telegraphic signals to the receiving station. At the latter is disposed a similar wire which picks up these waves. The resistance alterations of a coherer serve as a reagent to the electrical oscillations of the receiving wire.

Of late, Slaby and Count Arco succeeded in introducing a progress in the art of spark telegraphy in that they tuned a sending and a receiving wire to each other. The circumstances that such tuning is feasible admits of the presence of regular oscillations of definite frequency in the wires. Then, as would be suggested by the acoustic analogy and has been confirmed by experiments made on electric resonance, the "intensity" of resonance or consonance

the receiving wire would essentially be a function of the frequencies and the decrements (of damping) of the natural periods of the two wires. If the damping of the transmitter is marked, and that of the receiver low, then the receiver will oscillate at the frequency of its own natural oscillations irrespective of what may be the frequency of the transmitter; if, on the contrary, the damping of the receiver is great in contrast to that of the transmitter, the receiver will be caused to vibrate at the frequency of the incident waves. If tuning as pure as possible is to be attained, then not only the frequencies of both outfits will have to be consonant, but at the same time the damping should be diminished.

Now, the question may be posed as to what factors are decisive so far as the damping of electrical oscillations is concerned? In the case of a.c. of low frequency, it is primarily the line resistance of the wires; but at high frequencies such as are used in spark telegraphy, the damping due to radiation plays a by no means inferior role. The waves which serve as the carriers of telegraphic signals convey a certain amount of energy; this energy is withdrawn from the oscillations of the sending wire, and the amplitudes thereof are thus caused to be diminished more and more. The damping due to radiation therefore is inevitable in spark telegraphy.

The methods known from theoretical electrodynamics make it possible to estimate the various damping factors. They govern the distribution of the current along the wire, the propagation of waves in the ether, the radiated energy and the energy dissipated in the conductor.

The first query; In what way do electric waves propagate along a conducting wire, and of what effect is the free end? The laws underlying the propagation of electrical disturbances along an infinite wire possessing high conducting powers, formally speaking, are in agreement with the known motional

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laws of the stretched wire. However, the physical nature of the two phenomena would be substantially dissimilar. For in the case of a mechanical wave, the seat of the vibrational energy would be in the very wire, while for the electric wave it is in the surrounding ether. The wire here serves merely for the conducting away of the waves; the electrical current is confined to the outermost boundary layer of the conductor, the interior of which being screened from the electrical and the magnetic forces. Now, it may be asked, what happens when the wave reaches the free end F of the wire (Fig. 1)? In the case of the mechanical wave, complete reflection takes place. Is the electrical wave also simply reflected at the free end? At first blush, this might be thought impossible, for the wave continues propagating beyond AFB into ether. In what way will this circumstance effect the oscillatory phenomenon?

The Author, in two articles, has made an attempt to explain the phenomena in the field of a free-ended conducting wire looked at from the viewpoint of Maxwell's theory. The first study (1) dealt with the natural oscillations of a wire of finite length, whereas the second study (2) more exhaustively deals with forced oscillations of a unilaterally bounded wire and proves the agreement between the theory and the present observations. It was found that the assumption of complete reflection at the free end is approximately fulfilled. The disturbing effect of the free end essentially resides in a slight distortion

(1). Wied. Ann. 66, [illegible]-472, [illegible], later referred to as I

(2). Drude's Ann. 2, [illegible]-61, 1900, later referred to as II

of the waves (3). If the waves are of a definite frequency, then standing oscillations are produced, with a current node being located at the free end. At intervals each of a half-wave length there arises another node of the current. The displacement of the node positions in the vicinity of the free end is very slight (4). The wire may be cut at a second place but this second place must be at a nodal point of the current if it is desired to preserve the wave system on the now bilaterally bounded wire. Hence, the double length of the wire is an integral multiple of the wave-lengths of its natural oscillations. This finding corresponds to that of Slaby and the basic notion adopted by him respecting the distribution of the current in the sending and the receiving wires.

If, then, this assumption respecting the current distribution confirmed by theory be accepted, it will be possible to survey the course of the radiation process in spark telegraphy without any undue amount of mathematical auxiliaries. I beg to explain this situation by the simplest example. The results of the approximation method are in proper agreement with the exact theory previously suggested by this Author.

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(3). II pp. 33, 40

(4). II pp. 36,36

Translation of

SPARK TELEGRAPHY AND ELECTRODYNAMICS, by M. Abraham.

(Published in the Physikalische Zeitschrift, No. 22, March 2, 1901, 2. Jahrgang, pages 329 to 334. This translation begins at the second paragraph of the second column on page 330 and ends at the first paragraph of the first column on page 332.)

A wire EF (Fig. 2) of length l rises vertically upwards from the earth. The earth is to be considered a perfect mirror for electric waves.

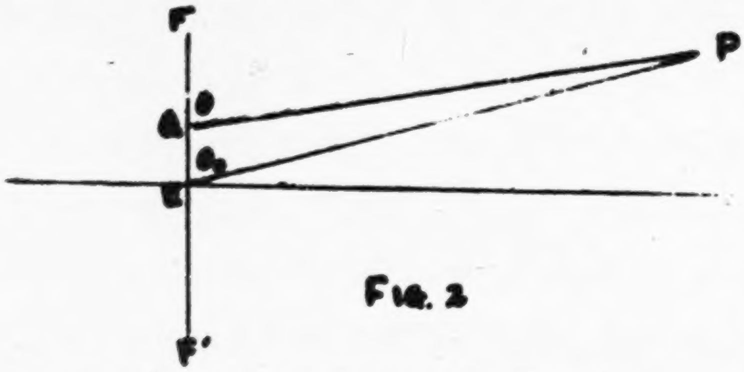

Fig. 2

The earth point E is a node of electric potential. The wire is now reflected with respect to the earth's surface and the potential distribution is chosen in such a manner that the opposite potentials are prescribed by two corresponding reflected points, one on either side, thus is the electromagnetic field of the wire EF above the earth identical with that of the wire FF' of length 2l oscillating in free space.

Therefore, we investigate the natural oscillations of a wire which has a node of potential at the middle point E and, consequently, an antinode of current; these are the odd numbered natural oscillations. Its current distribution is determined by

$$\mathfrak{J} = a\cos\left(\frac{\pi n}{2l}\mathfrak{z}\right)\cdot\sin\left(\frac{\pi n c t}{2l}\right)$$

$$-l \leqq \mathfrak{z} \leqq +l.$$

Here z expresses the height of any section Q above the middle point E of

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the wire, t the time, c the velocity of light, a the amplitude of the current oscillations at the antinode of current. An odd positive whole number is to be substituted for n which designates the ordinal number of the oscillation. This swiftly changing current now sends out waves of electromagnetic induction.

The electromagnetic field of an oscillating current element has been determined by H. Hertz. Let Q be the middle point of the current element J ds. Furthermore, let P be a point in space whose distance PQ = r from the current element is large compared with the wavelengths of the oscillations. Then the electric force (E) lies in the plane including PQ and the wire, and is perpendicular to PQ; the magnetic force (H) is perpendicular to that plane. The intensities of both forces are determined by

$$E = H = -\frac{d}{dr}\left(\frac{J\left(t-\frac{r}{c}\right)}{r}\right)\cdot dy\cdot \sin\theta$$

$$= a\cdot\frac{\pi n}{2l}\,dy\cos\left(\frac{\pi n y}{2l}\right)\,\frac{\cos\frac{\pi n}{2l}(ct-r)}{r}\;\sin\theta$$

The disturbance leaving Q at time $\left(t-\frac{r}{c}\right)$ arrives at P at time (t). This is a deduction from the general equation which states that electric induction is propagated with the velocity of light.

The magnetic forces which come from the individual current elements are pointed in the same direction, namely, perpendicular to the plane EPP. Likewise the electric forces do not deviate appreciably in direction if we make the assumption that r is large compared with the sum of all the wave-lengths of the natural oscillations, i.e., large compared with 4 l.

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For the differences in direction of straight lines drawn to the individual current elements diminish with the increasing distance from the wire. Accordingly, the electric forces sent out from the individual current elements are perpendicular to the straight line EP drawn through the middle point E. Let r_0 be the length, θ_0 = PEF the angle, which it forms with the wire axis. Then with this approximation we have

3) $$r = r_0 - z\cos\theta_0$$

4) $$H = E = a\cdot\frac{\pi n}{2l}\cdot dz\cos\left(\frac{\pi n z}{2l}\right)\frac{\cos\frac{\pi n}{2l}\left(ct - r_0 + z\cos\theta_0\right)}{r_0}\cdot\sin\theta_0.$$

Now all the electric and likewise all the magnetic forces coming from the individual current elements are superposed. For the equations linking the electromagnetic field in the aether and the current in the conductor are linear equations. Accordingly, one obtains for the resultant intensity of the electric and magnetic force at a distance r_0 from the middle point of the wire large compared with 4 l

5) $$H = E = a\cdot\frac{\pi n}{2l}\cdot\frac{\sin\theta_0}{r_0}\int_{-l}^{+l}dz\cos\left(\frac{\pi n z}{2l}\right)\cdot\cos\frac{\pi n}{2l}\left(ct - r_0 + z\cos\theta_0\right).$$

Since n is odd, we have

$$\int_{-l}^{+l}dz\cos\left(\frac{\pi n z}{2l}\right)\cos\left(\frac{\pi n z\cos\theta_0}{2l}\right) = \frac{4l}{\pi n}\cdot\sin\left(\frac{\pi n}{2}\right)\frac{\cos\left(\frac{\pi n}{2}\cos\theta_0\right)}{\sin^2\theta_0}$$

and we obtain

$$6)\quad H = E = 2a(-1)^{\frac{n-1}{2}} \cdot \frac{\cos\frac{\pi n}{2l}(ct - r_0)}{r_0} \cdot \frac{\cos\left(\frac{\pi n}{2}\cos\theta_0\right)}{\sin\theta_0}$$

This electromagnetic field corresponds to a spherical wave, which spreads out rapidly from the middle point of the wire. We consider a sphere r_0 = constant, and construct circles of longitude and latitude where we regard as the poles the points at which the extensions of the wire axis pierce the sphere. The magnetic force is everywhere in the direction of the circles of latitude, the electric force being oriented in the direction of the meridians. Both are perpendicular to the direction of propagation of the wave. The intensities of the forces vary with the latitude θ_0 according to the equation

$$\frac{\cos\left(\frac{\pi n}{2}\cos\theta_0\right)}{\sin\theta_0}$$

Accordingly, for the fundamental oscillation (n = 1) the amplitudes reach their maximum value at the equator ($\theta_0 = \frac{\pi}{2}$). The most intense rays are sent out perpendicular to the wire axis. At the pole ($\theta_0 = 0$) the intensity is zero. For the fundamental oscillation the amplitude constantly diminishes from the equator to the poles. The harmonic oscillations, on the contrary, possess still other minima and maxima. The minima lie in the latitude circles determined by

$$\cos\theta_0 = \pm\frac{m}{n} \quad (m \text{ odd})$$

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Since according to equation (1) the positions of the current nodes in the wire are given by $\frac{z}{l} = \pm \frac{m}{n}$, the node lines of the sphere can be found by the following construction. Hyperboloids are drawn through the current nodes in the wire and their foci fall at the ends of the wire (F,F'). Their asymptotic cones cut the sphere in the node lines. The node lines mark the boundary lines of zones of oppositely phased oscillations on the sphere.

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What energy is radiated into the ether by the waves? Clues may be found on this question by the aid of a law of electrodynamics advanced by Poynting which states that the energy flows at right angles to the electric, and magnetic forces. If, more particularly as in our own case, those two vectors are at right angles to each other, then the amount of energy flowing each second through a square centimeter of area of our sphere is

- (see text for equation) -

Integrating for the entire area of the sphere, this aggregate radiation is found:

- (See text for equation) -

The definite integral here arising can be converted into the following series: - (See text for equation) -

This last-mentioned definite integral I have designated by C_n (1) and for the same the following formula has been derived (1):

- (See text for equation) -

For the fundamental oscillation this formula results in

- (See text for equation) -

For the harmonics (n = 3,5,7,etc.) it furnishes with sufficient closeness:

- (See text for equation)-

Now, the total radiation per second becomes:

- (See text for equation) -

The energy which is extracted from the field of the oscillating wire in the time of a full cycle ($\tau = \frac{4l}{cn}$) is

- (See text for equation) -

With growing ordinal number n, in the presence of unvaried amplitude α of the current variations in the current loops, the energy radiated off during one oscillation constantly diminishes.

(1). I pp. 460,461

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In order to ascertain the damping which is a result of radiation we must in addition calculate the electromagnetic energy of the oscillating wire itself.

The magnetic energy of a wire traversed by a uniform flux is

- (See text for equation) -

where L is the coefficient of inductance of the wire. In the practical application of this formula, we will in the first place have to keep in mind that, generally speaking, electric energy exists side by side with the magnetic energy. But if we pick the instant of crest current when according to equation (1)

- (See text for equation) -

then the electrical energy vanishes since momentarily no electrical charges exist on the wire. However, what must be kept in mind in the second place is that the flux is not uniform, indeed, that it changes from one cross-section to the next. It would be easy to form an average for the square of the current:

- (See text for equation) -

and thus to put

$$T = \frac{1}{2} La^2$$

Since the flow is confined to the surface layer the coefficient of self induction assumes value

- (See text for equation) -

where is the radius of the wire cross-section.

If, then, (9) which is the amount which is lost by radiation during a cycle be divided by (10) standing for the aggregate energy, the

following result is obtained:

In the course of a whole oscillation this fraction

- (See text for equation) -

of the energy is dissipated by radiation.

The logarithmic decrement of the oscillation amplitudes therefore is

- (See text for equation) -

It is very remarkable that the result of the complete estimate almost strictly agrees with the formula which an exact theory furnishes in first approximation for the logarithmic decrement of the damping of radiations, and which reads:*

- (See text for equation) -

Putting here

- (See text for equation) -

it will be noted that the departure from formulae (12) and (13) is very slight for wire dimensions such as occurring in practice.

We shall now calculate for a concrete case the amount of radiation damping numerically. Suppose we have a wire whose length is l = 50 meters, and whose cross-sectional radius = 0 .5 mm. Then

- (See text for equation) -

In the light of (8a) and (13), the decrement for the fundamental wave becomes:

- (See text for equation) -

* - 1 p.407 equa. 23a. $\mathcal{E}$ is determined by equa. 17a, p.451. There the length of wire is 2 and the radius of the cross section b. The formula $\mathcal{E}$ = 4 ln (l/ρ) applies generally because in accordance with I, p.456, geometrically like conductors have the same logarithmic decrement.

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On the other hand, the decrement of the damping shall be calculated which the oscillations experience as a result of line resistance in the wires. The absorption of waves which propagate along a line wire has been investigated by A.Sommerfeld.* In our instance, the approximate formula** will suffice which for the fundamental wave furnishes the logarithmic decrement:

- (See text for equation) -

where μ is the (magnetic) permeability, C the conductance measured in terms of absolute electromagnetic units. For copper wire there is

$\mu = 1$, $C = 6 \times 10^{-4}$. Hence

- (See text for equation) -

While as a result of heat dissipation in the wire the amplitude would decrease to the 2.718[th] part of its initial value after only 80 cycles, this same decrease is caused by radiation already after 5 cycles.

This finding is by no means surprising. For, as above pointed out, it is distinctly desirable so far as the purpose of spark telegraphy is concerned, that the energy should not be lost as a consequence of absorption inside the conductor, but should be caused to be radiated off in order to utilize the same for telegraphic signals and their transmission.

* A. Sommerfeld, Wied. Ann. 67, 233-290, 1899

** l.c.S. p.276, $X\lambda_0$ is here equal to $u_1 \cdot \lambda_0 = 4\,l$

In laboratory experiments, on the contrary, arrangements have frequently been used in which the radiation loss is diminished as much as possible in order to avoid disturbances occasioned by reflections on the wall of the room, and, on the other hand, in order to secure oscillations persisting for a long while. The electric waves have been guided along two parallel wires (CD, C'D', Fig. 3), being spaced apart a distance that is small compared with the wavelength in such a way that two opposite points Q, Q' of the two wires were caused always to oscillate in phase opposition. Both of the opposite current elements then furnish or contribute equal and opposite values to the intensities of the electrical and the magnetic force of the emitted wave. Hence, the radiation in such a closed system is insignificantly small when contrasted with the radiation of a single freely oscillating wire (1).

It has been found that in a vertically rising wire the decrement of the fundamental wave may not be diminished below 1/5. Prof. Slaby and Count Arco have used for the receiver also an arrangement in which from the grounding point E a line EK being horizontal and of like length as the vertical was used which at its free end K, at the point of maximal potential, was fitted with the coherer.

(1) The same thing applies to oscillations produced by the discharge of a Leyden jar. As stated by Prof. Braun in a recent paper such oscillations are also successfully used in wireless telegraphy. A much smaller fraction of the oscillating energy will thus be utilized in the transmission of the signals but the tuning seems to be more perfect. V/23

In this instance, there holds good for the horizontal wire EK what has just been stated. If it is close to the surface of the earth, it furnishes conjointly with its image E'K' in reference to the surface of the earth, no appreciable contribution to the radiation. On the contrary, the horizontal line contains a quantity of electromagnetic energy which is at least equal to that of the vertical line or wire. In this disposition the loss due to radiation at most may be deemed to be 1/10th.

Although the method here used would, a priori, not appear free from objections, the agreement between the results thereby found and the findings of the exact theory demonstrates and justifies its raison d'être. In fact, it is likely that the same could successfully be employed also in the case of more complicated arrangements in which the exact theory is a failure.

TRANSLATION

A.D.P., February 23, 1937 -

MEASUREMENTS IN THE RADIATION FIELD OF ROD-SHAPED ANTENNA ENERGIZED IN THE FUNDAMENTAL AND HARMONIC FREQUENCIES

By L. Bergmann

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6. A linear antenna energized in its third harmonic.

The total length of antenna $2l = 344$ centimeters. Since we are dealing with an even number harmonic and there is therefore a current node in the middle of the antenna, the excitation was not symmetrical. Fig. 22 shows the current distribution on the antenna and the position in which the sender excites the antenna is specially indicated. The dotted curve interconnecting small circles illustrate the experimentally determined radiation diagram. The curve indicated in full lines is calculated in accordance with the equation

The total radiation of the antenna falls into four parts. The radiation will be 0 for the values; $\cos\theta = 1, 1/2, 0$, i.e., for $\theta = 0^\circ$ (direction of antenna), $\theta = 60^\circ$, $\theta = 90^\circ$ (equatorial plane), $\theta = 120^\circ$ and $\theta = 180^\circ$ (antenna direction). The experimental data corresponds perfectly with the calculations as far as the direction of the radiation is concerned. However, this is not true for the amplitude of the radiation lobes. In accordance with the calculation, the lobes inclined towards the equatorial plane should be substantially smaller in amplitude than the lobes radiated at a sharp angle with respect to the direction of the antenna. This relation is approximately true for the right half of Fig. 22; the larger lobe is

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somewhat small because the amplitude of the currents in the individual current loops on the antenna are different. On the other hand, in the other half of the radiation diagram, the positions of the two radiation components are interchanged. The reason for this is the unsymmetric excitation of the antenna producing different currents in the two halves of the antenna. The ratios are the same as in the above discussed case, in which the antenna was excited at its second harmonic. On account of the unknown current relations, these ratios can be calculated only with a great deal of trouble.

11. Rod-shaped Antenna excited by the Sixth Harmonic.

The length of the antenna which in this instance is excited again symmetrically in the middle was 7/2 λ= 602 cm. Fig. 28 shows the measured radiation diagram and the radiation diagram calculated by the equation:

-(See text for equation) -

The radiation of the antenna is here divided into seven parts. The number of the lobes of radiation produced, just as in the instances hereinbefore dealt with, is always in agreement with the number of current loops existing along the aerial. Zero places of radiation are at cos = 1, 5/7, 3/7. 1/7, 0, i.e., at = 0 degree (direction of antenna), 44°25', 64°36', 81°48', or the places corresponding to the mirror images in reference to the equatorial plane. The presence of these zero points and of the corresponding lobes of radiation is exactly confirmed by the measurements. Discrepancies are found only as regards the energy amplitudes radiated off from the various lobes. The major part of the energy, however, just as in the previous case, is given off at an acute angle to the antenna direction. It is just these last two cases which go to show that in the transmission on short waves it is feasible by the use of an antenna being positioned perpendicular to the surface of the earth, and which is excited by a harmonic, to cause the major portion of the energy to be radiated off obliquely in upward direction at an acute angle in reference to the direction of the aerial. This portion of the energy leaves the antenna in the form of a space wave. When working with waves of great length, on the contrary, we are mostly dealing invariably with a surface radiation seeing that the antenna, for reasons of the great antenna height which is not realizable in actual practice, is unable to be excited by harmonics.

1. There is described the construction of a tube transmitter for the generation of undamped oscillations with a wavelength of 172 cm. which is arranged to excite a rod-shaped conductor antenna in any of its even and odd numbered harmonic periods.

2. By means of a specially constructed receiver, the radiation field is measured of an antenna excited respectively in its fundamental and different harmonic periods. The measurements are carried up to the excitation of the antenna in its sixth period.

With excitation at the fundamental period, the entire radiation is perpendicular to the antenna in its equatorial plane. But when one proceeds to excitation in the harmonic periods there results radiation from the antenna in several directions, and, in fact, there are just as many directions of radiation as there are current antinodes over the whole antenna. There is very good agreement between the measured radiation diagrams and the radiation curves calculated by the Abraham equations in respect to the direction of the radiation branches. For the amplitude of the energy radiated in the separate directions there is, on the contrary, a departure between calculation and measurement. The reason lies in this, that hitherto in calculating it was always assumed the the current amplitude in the individual oscillating antinodes on the antenna all had the same value. In reality, however, the current amplitude in that current

ll V/21

antinode where the excitation by the transmitter takes place is substantially greater than in the neighboring current antinodes. When this is considered in the calculation, then the amounts of energy transmitted in the individual directions is in agreement with the measured values also in regard to amplitude.

3. In several cases, by the insertion of coils, the radiation from individual antinodes is suppressed and thereby a special radiation diagram results which is, nevertheless, in agreement with the calculations.

4. The results obtained are of practical value because today wireless telegraphy is carried on over great distances by the use of short waves of less than 100 meter wavelengths. By exciting the transmitting antenna in harmonic periods one can send out the greatest part of the radiated energy, not as hitherto with the long wavelengths perpendicular to the antenna and, consequently, parallel to the earth's surface, but at more or less of an angle with the antenna and, accordingly obliquely upwards, and thereby to radiate directly skyward which is especially well suited for the propagation of short waves.

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TRANSLATION - Annalen Der Physik - 1926 - Pages 425-453.

A RADIATION FROM COMPLICATED RECTANGULAR ANTENNAE WITH SIMILAR RADIATORS

By M. A. Bontsch-Bruewitsch

I. Radiation Resistance.

a) By a complicated antenna will be meant an aerial which consists of a number of radiators and a system of wires by means of which the energy is supplied. By a rectangular antennae the author means those in which the wires are arranged only in three mutually perpendicular directions. Accordingly the axis of these radiators are directed in one of these three directions.

The radiation resistance of an antenna or this kind may, in general, be defined as the ratio of the radiated power P to the square of the sum of loop currents in the various radiators. In the case of n similar radiators through which flow equal currents this resistance

$$R = \frac{P}{(n i)^2} \tag{1}$$

In general the losses divide themselves among the radiators unequally. In practice it is often preferable to deal with the average value of radiation resistance of each radiator. This average value may be determined as follows:

$$r = \frac{P}{n i^2} = n R \tag{2}$$

Before we proceed with the discussion of radiated power from antenna systems, we wish to emphasize the following fact: If r_0 is the radiation resistance of a single isolated radiator and r is the corresponding resistance of the same radiator when it is functioning in conjunction with other radiators in a complicated antenna then $r_0 \neq r$ as long as there is

v/1.

interaction among the radiators which results in new electromotive forces. These electromotive forces could be calculated independently of the distribution of radiation and thus r could be determined without any knowledge of radiated power. On the other hand, when determining the resistance from the radiated power it is necessary and sufficient to know only this power. From this point of view, the distribution of radiation in space is quite immaterial. This distribution could be changed by any secondary causes whatever, still as long as the radiated power remains the same the radiation resistance of the antenna does not vary. In other words the resistance remains the same as long as there is no interaction among the aerials of the system which would influence the radiation in space.

This remark holds equally true in case of the action of the earth which always, more or less, influences the distribution of radiation of an antenna. The influence of the earth on the radiation resistance can be considerable only in the case when the antenna is near the earth.

It is often assumed when calculating the radiation resistance of a conductor that the earth is a perfect conductor and that the antenna is strung quite near the earth. This however corresponds to no actual case when working with short waves for such antennas are elevated high above the earth and the earth itself cannot be considered as an approximately perfect conductor.

One may minimize these errors by treating the earth as an external mirror which is arranged in any fashion whatever and which has a certain definite absorbtion coefficient. The advantage of this mode of treatment lies in that it makes possible to apply the analysis for dealing with distribution of radiation as well as the calculations of resistance for any practical cases.

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When calculating the power we shall first assume that the aerial is removed far from the earth. The influence of the earth will be introduced later. The following method will be used in calculating:

Let us imagine that there are a number of dipoles of infinitesimal dimensions and at distances of half a wave length from one another at the center of a sphere, the diameter of which is so large that one may neglect the dimensions of the dipole system. The radiators are arranged along the axis SS_1 (Fig. 1) and the axes of these radiators are at right angles to the equatorial plane of the sphere. Let θ be the angular distance between N_1 and N and α, the azimuth of the great circle $N N_1$ perpendicular to SS_1 be chosen as the coordinates of N_1.

Since the radius of this sphere has been shown to be so very large in comparison with the dimensions of the dipole system, we may regard the lines joining N_1 with the various dipoles as parallel. Let it be assumed that the oscillations of the dipoles are in phase and that these dipoles in phase and that these dipoles have equal moments. Let the amplitudes of the vectors which are produced by the individual dipoles on the surface of this sphere be $h_0 = f(\alpha, \theta)$. Then at point N_1 with coordinates α_1, θ_1, the magnetic component of the pointing vector due to the first dipole is

$$h_0 \sin \omega t = f(\theta_1, \alpha_1) \sin \omega t$$

The corresponding component due to the second dipole is

$$h_0 \sin(\omega t + \beta)$$

Where β is the difference in phase which corresponds to the difference in path l see (Fig. 2)

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$$\beta = \frac{2\pi l}{\lambda}$$

The third dipole produces

$$h_0 \sin(\omega t + 2\beta) \qquad etc.$$

The resultant vector is

$$H_0 \sin\left\{\omega t + \frac{\beta(n-1)}{2}\right\} = h_0\left\{\sin \omega t + \sin(\omega t + \beta) + \cdots + \sin[\omega t + \beta(n-1)]\right\}$$

By applying the series expansion

$$\frac{\sin nx \cdot \sin(n-1)x}{\sin x} = \sin 2x + \sin 4x + \sin 6x + \cdots + \sin 2x(n-1)$$

and by putting $\omega t = 0$ we obtain the ratio of the amplitude or the root mean square value of the resultant vector to the sum or the root mean square of the sum of the components:

$$(3) \qquad \frac{H_0}{h_0} = \frac{H}{h} = \frac{\sin \frac{n\beta}{2}}{\sin \frac{\beta}{2}} = Y_1$$

This quantity shall be called the phase factor and the function $Y = \psi(\alpha, \theta)$ which defines this phase factor, will be called the phase function. The form of this function depends on the number and on the arrangement of the radiators. Presently it will be shown that for all points along the arc of a small circle which is perpendicular to the axis SS_1 of the sphere the phase factor has the same value.

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Let us take another point M_2 somewhere on the arc of this type (Fig. 1 and Fig. 3) then GM_2 makes the same angle with SD_1 as the one made by GM_1 and therefore it is clear that the phase difference between the vectors due to any two neighboring radiators is the same as in the preceding case.

Accordingly,

$$H'_0 \sin\left[\omega t + \gamma + \frac{\beta}{2}(n-1)\right] = h'_0\left[\sin(\omega t + \gamma) + \sin(\omega t + \gamma + \beta) + \cdots + \sin(\omega t + \gamma + \beta(n-1))\right]$$

Hence;

$$(4) \qquad \frac{H}{h'} = \frac{\sin\frac{n\beta}{2}}{\sin\frac{\beta}{2}} = Y_1$$

Now we wish to show that in the case of a linear conductor in which the current is distributed symmetrically with respect to the midpoint, the phase of the ve produced by the complete antenna is exactly equal to the phase produced by th current elements located at equal distances from the two ends of the antenna. The current amplitude along the length 2L of the conductor AB (Fig. 4) may be defined as a function $i_0 = f(x)$, where (x) is the distance from the mid-point. The magnetic vector at a distant point M such that the line joining it with the center of this sphere makes angle θ is given as follows:

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$$(5)\quad \begin{cases} h = A \int_0^{l} f(x)\left[\sin(\omega t+\varphi) + \sin(\omega t-\varphi)\right] dx = \\ = \left[2A \int_0^{+l} f(x)\cos\varphi \, dx\right] \sin\omega t = \beta \sin\omega t \end{cases}$$

here $\varphi = \frac{2\pi}{\lambda} x \cos\theta$

elementary vector produced by an element of the conductor dx (when x = 0)

the same time M is

$$(6)\quad dh = \left[A f(0)\cdot dx\right] \sin\omega t = \beta_1 \sin\omega t$$

parison of (5) and (6) shows that the two vectors differ in amplitudes

t have the same phases. Thus, when one is trying to determine the phase

ation of some antennae which satisfy the aforementioned conditions it is

sible to replace the antennae by dipoles situated at their mid-points.

se dipoles should be assigned the phases of the mid-points of the antennae.

t us assume a linear antenna made up of identical elements which are so

ranged that their mid-points are at equal distances d from each other and,

reover, that within the limits of each element the condition of symmetrical

istribution of current about the mid-point is fulfilled. We shall replace

h individual section by a dipole located at its mid-point. The resultant

ctor then is

$$H \sin\left(\frac{n-1}{2}\beta\right) = h\left(\sin\beta + \sin 2\beta + \cdots + \sin(n-1)\beta\right)$$

ere N is the number of sections, h- the vector due to each dipole,

$$\beta = \frac{2\pi d}{\lambda}\cos\theta^\circ + \zeta$$

e angular phase difference between the component vectors, ζ - the

ase displacement between the current in any two neighboring dipoles.

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When $\theta = \frac{\pi}{2}$; $\beta = \zeta$ and the phase of the current in the dipole at the middle of the whole antenna and equivalent thereto is, with reference to the first element, given by

$$\frac{(n-1)}{2}\zeta$$

In view of the preceding, it is possible to obtain the phase function of a system of antennae of this kind by replacing each individual wire by a dipole located at its center and oscillating with phase

$$\Delta = \gamma + \frac{(n-1)}{2}\zeta \qquad (7)$$

where γ is the phase of the current in the first element of the individual wire.

b) Let us consider a system of n vertical radiators each of length $\frac{\lambda}{2}$ arranged in horizontal line. Let the distance between any two radiators be $\frac{\lambda}{2}$. Let all radiators oscillate in the same phase. Let us assume that this system is located at the center of a large sphere (Fig. 1) and that the axes of all radiators are directed toward the pole and that the line which joins the centers of the radiators coincides with the diameter SS_1 for $\alpha = \frac{\pi}{2}$. It is known that for every conductor of length $\frac{\lambda}{2}$ the amplitude of the magnetic vector on the surface of the sphere is

$$h = \frac{2i}{\rho c_0} \qquad (8)$$

where i is the loop current, ρ the radius of the sphere and c_0 the velocity of light. In the case of n equi-spaced radiators at the center of the sphere

$$H = nh\,\psi(\theta, \alpha)$$

If we integrate the pointing vector over the surface of the sphere we obtain

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total power of radiation:

$$P = \frac{\eta^2 i^2}{c_0 \pi} \int_0^{\alpha = 2\pi} \int_0^{\theta = \pi} \frac{\cos^2\left(\frac{\pi}{2}\cos\theta\right)}{\sin\theta} \varphi^2(\theta, \alpha)\, d\alpha \cdot d\theta.$$

i is in absolute electrostatic units. In order to convert these units the practical units it is necessary to multiply the right-hand side by c_0 and then P will be expressed in watts. The resistance of the whole tem is obviously $R = \frac{P}{(ni)^2}$ While the power due to a single na $p = \frac{P}{n}$ and its resistance (average value) $r = \frac{P}{n i^2}$ subsequent numerical values which follow are given for this latter quantity.

Now we wish to find the phase function. It is obvious that at t E_1 on the equator whose coordinates are

$$\alpha_1 = 0 \quad \text{and} \quad \theta = \frac{\pi}{2}$$

magnetic vectors add algebraically when this sphere is sufficiently large that the phase differences are zero. The mean square value of the resulting etic vector at this point is $H = nh$ where h is the value of the vector to a single radiator. If one moves along the equator because of the isions of α_1, the resultant vector also varies for there arise phase differs between fields produced by the individual radiators. The phase difference en the vectors due to two neighboring radiators is

$$\beta = \frac{2\pi l}{\lambda} \sin\alpha_1 = \pi \sin\alpha_1$$

the help of equation (8) we have

$$\frac{H}{h} = \frac{\sin\left(\frac{\pi n}{2}\sin\alpha_1\right)}{\sin\left(\frac{\pi}{2}\sin\alpha_1\right)} \qquad (9)$$

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This is the phase factor for the points on the equator. In order to determine the phase factor for any arbitrary point M on the sphere, it is necessary to find the equatorial coordinate of the arc of the small circle which passes through the point and which lies in a plane perpendicular to the axis MM_1. The value so found must be substituted into equation 9. If M is projected on the equatorial plane (Fig. 5) it is found that $OM = \rho \sin\theta$. Where ρ is the radius of the sphere; moreover, as it is obvious from the drawing we have

$$\sin\alpha_1 = \sin\theta \cdot \sin\alpha \qquad (10)$$

By substituting from this relation into equation (9) we obtain the value of the desired function on the surface of the sphere

$$Y_2 = \frac{\sin\left(\frac{\pi n}{2}\sin\alpha \cdot \sin\theta\right)}{\sin\left(\frac{\pi}{2}\sin\alpha \cdot \sin\theta\right)} \qquad (11)$$

The power radiated from the system in question is

$$P = \frac{60\,i^2}{\pi}\int_0^{\pi}\int_0^{\pi} \frac{\cos^2\left(\frac{\pi}{2}\cos\theta\right)}{\sin\theta}\, y_2^2\, d\alpha\, d\theta \qquad (12)$$

An approximate graphical calculation yields:

n	2	3	4	5
r	58	62	57	70 Ω

When the number of antennas is large, the total radiation is concentrated within a narrow ring delimited by arcs of two small circles which are parallel to the main meridian plane. (Fig. 6).

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By regarding the surface of this ring as being approximately [cy]lindrical we may put $\sin\alpha = \alpha$ and obtain

$$H = \frac{2(n\,i)}{c_0\,\rho}\,\frac{\cos\frac{\pi}{2}\cos\theta}{\sin\theta}\cdot\frac{\sin\frac{\pi n\alpha}{2}}{\frac{\pi}{2}\alpha} \qquad (13)$$

[On] account of the smallness of θ the phase function does not depend upon [...]

$$dP = 2\pi\rho^2\,\frac{c_0 H^2}{4\pi}\,d\alpha\,.\,d\theta$$

[Hen]ce, when one uses practical units one obtains

$$P = \frac{60\,n^2 i^2}{\pi}\int_0^{\pi}\frac{\cos^2(\frac{\pi}{2}\cos\theta)}{\sin^2\theta}\,d\theta\cdot 2\int_0^{+\frac{2}{n}K}\frac{\sin^2\frac{\pi n\alpha}{2}}{\left(\frac{\pi n\alpha}{2}\right)^2}\,d\alpha \qquad (14)$$

[Th]e limits of the second integral are to be determined in the following manner: [th]e border-line of the main ray corresponds to $\alpha = \frac{2}{n}$ for then the integrand [p]asses through zero for the first time. The other rays are marked out by [...] determined by $\alpha = \frac{4}{n}, \frac{6}{n},$

[S]ince the energy of the side rays rapidly decreases with the order number of the [ra]y one may consider only an arbitrary number of rays K and neglect the energy [o]f the remaining rays. In so doing K/n remains small, for n may be chosen to [b]e arbitrarily large. Let

$$\frac{\pi n\alpha}{2} = z$$

then

$$P = \frac{120\,i^2 n}{\pi^2}\int_0^{\pi}\frac{\cos^2(\frac{\pi}{2}\cos\theta)}{\sin^2\theta}\,d\theta\cdot 2\int_0^{K\pi}\frac{\sin^2 z}{z^2}\,dz \qquad (15)$$

The first integral may be expressed as follows:

$$\int_0^{1}\sqrt{1-u^2}\;\cos\pi u\;du \qquad (16)$$

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This is Bessel function J_1 whose value may be obtained from tables * (see footnote). Its value is approximately 1.4.

The second integral may be transformed into integral cosine with double limits, and when Z is large, it is approximately equal to $\frac{\pi}{2}$. Therefore

$$r = \sim 56\,\Omega$$

c.) Let us now consider an antenna of the same kind in which the phases in the neighboring vertical wires are 180° apart. These antennas produce a main ray in the direction of the base line. In order to obtain the maximum radiation when $\alpha = 0$ the base line must be directed at right angles to the axis BB_1. It may be shown that in this case the phase function

$$Y_\theta = \frac{\sin\left[\frac{\pi n}{2}(1-\cos\alpha\sin\theta)\right]}{\sin\left[\frac{\pi}{2}(1-\cos\alpha\sin\theta)\right]} \qquad (17)$$

Accordingly the power will be

$$P = \frac{60 i^2}{\pi}\int_0^\pi\int_0^\pi \frac{\cos^2\left(\frac{\pi}{2}\cos\theta\right)}{\sin\theta}\, Y_\theta^2 \, d\theta\, d\alpha \qquad (18)$$

An approximate, graphical calculation yields:

n =	2	3	4
r	58	95	100 Ω

When n is large expression (18) may be replaced by a simpler one. In the system under consideration the main ray, as well as the side rays, are delimited by cones the vertices of which are located at the center of the sphere while

*) E. Jahnke und F. Emde, Funktionentafeln.

their axes coincide with the base line of the antennas. The traces of intersection of these cones with the sphere are circles. (Fig: 7) In that portion of the sphere which is delimited by such a circle which corresponds to the number K say, the Poynting Vector may be taken to be constant and equal to

$$\Pi = \frac{(n i)^2}{c_0 \rho^2 \pi}$$

and $(\sin\alpha)$ may be replaced by α. If the whole surface is sub-divided into rings

$$dS = 2\pi \rho^2 \alpha \, d\alpha$$

one obtains

$$dP = \Pi \, dS \, Y_4^2$$

the phase function may be written as follows

$$Y_4 = \frac{\sin\left[\frac{\pi n}{2}(1-\cos\alpha)\right]}{\sin\left[\frac{\pi}{2}(1-\cos\alpha)\right]} = \frac{\sin^2 \frac{\pi n \alpha^2}{4}}{\left(\frac{\pi n \alpha^2}{4}\right)^2} = \frac{\sin^2 z}{z^2}$$

then

$$P = \frac{240\, n i^2}{\pi} \int_0^{n\pi} \frac{\sin^2 z}{z^2} \, dz$$

For large values of K in accordance with the aforesaid

$$r \approx 120 \, \Omega$$

d.) Now we shall consider two more types of stacked antennas composed of vertical radiators of lengths $\frac{\lambda}{2}$ and directed parallel to the same axis. In the antennas of the first kind all radiators vibrate in the same phase while in the antennas of the second kind the phases of neighboring radiators differ by 180°. It is clear that in this vertical arrangement of antennas the foregoing questions in regard to the phase function still hold good. The difference consists only in that in this

case the zones of constant phase vectors lie not in vertical but in horizontal planes which are parallel to the equatorial plane. For this reason the distribution of radiation depends not on the azimuth but on the polar distance. By analogy with the previous reasoning we obtain for "in-phase" antennas

$$P = 60\, i^2 \int_0^{\pi} \frac{\cos^2\left(\frac{\pi}{2}\cos\theta\right)}{\sin\theta} \cdot \frac{\sin^2\left(\frac{n\pi}{2}\cos\theta\right)}{\sin^2\left(\frac{\pi}{2}\cos\theta\right)}\, d\theta - M \qquad (20)$$

by the series expansion

$$\frac{\sin^2(nx)}{\sin x} = \sin x + \sin 3x + \cdots + \sin(2n-1)x$$

when $x = \frac{\pi}{2}\cos\theta$ because of the relation $\sin x = \sqrt{1-\cos^2 x}$

integral (20) may be expressed in the following manner:

$$M = N_1 + N_2 + \cdots + N_n \qquad (21)$$

where $$N_k = A_k \int_0^{\pi} \frac{\cos^{2k}\left(\frac{\pi}{2}\cos\theta\right)}{\sin\theta}\, d\theta$$

let $\cos\theta = y$

$$N_k = \int_{-1}^{+1} \frac{\cos^{2k}\left(\frac{\pi}{2}y\right)}{1-y^2}\, dy = \int_{-1}^{+1} \frac{\cos^{2k}\left(\frac{\pi}{2}y\right)}{1+y}\, dy$$

Furthermore by putting $z = \frac{\pi}{2}(1+y)$ we obtain

$$N_k = \int_0^{\pi} \frac{\sin^{2k} z}{z}\, dz = \frac{(-1)^{k+1}}{2^{2k-2}} \left[\int_0^{k\pi} \frac{\sin^2 z}{z}\, dz - \right. \qquad (22)$$

$$\left. - 2k \int_0^{(k-1)\pi} \frac{\sin^2 z}{z}\, dz + \frac{2k(2k-1)}{1\cdot 2} \int_0^{(k-2)\pi} \frac{\sin^2 z}{z}\, dz - \cdots \pm B \int_0^{\pi} \frac{\sin^2 z}{z}\, dz \right]$$

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by introducing the abbreviation

$$\int_0^{a\pi} \frac{\sin^2 z}{z}\, dz = \overset{a\pi}{\underset{0}{S}} \qquad (25)$$

and expressing M_1, M_2, ... by means of S it is possible to transform the integral M in the following manner:

$$M = (-1)^{n-1}\, 60\, i^2 \left[\overset{n\pi}{\underset{0}{S}} - 4 \overset{(n-1)\pi}{\underset{0}{S}} + 8 \overset{(n-2)\pi}{\underset{0}{S}} - \cdots \pm 4(n-1) \overset{\pi}{\underset{0}{S}} \right] \qquad (26)$$

By applying Van der Pol's solution we obtain:

$$\overset{a\pi}{\underset{0}{S}} = \frac{1}{2}\left[E + \log_e 2\pi a - Ci\, 2\pi a \right] \qquad (27)$$

where E is Euler's constant .577... and Ci is the integral cosine which does not differ greatly from zero for all values of the arc equal to $n\pi$ (n is an integral number).

From formula (26) we find the following numerical values

2	3	4	5
90	103	100.6	103.5

When n is very large the value of P may be found in the following manner. The limit of the angle which includes the number K ray is determined by means of relation

$$\cos\theta = \frac{2K}{n}$$

where the value of K may be taken to be as large as desirable. If at the same time $\frac{K}{n}$ is very small $\cos\theta$ approaches zero and $\sin\theta$ approaches unity. Equation (2) then assumes the following form

$$P = \frac{240\, n\, i^2}{\pi} \int_0^{K\pi} \frac{\sin^2 z}{z^2}\, dz \qquad (28)$$

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and, as before, it yields the resistance of a single antenna in the presence of a large number of antennas, namely,

$$r = 120\ \Omega$$

In case of antenna of the second kind (harmonic)

$$P = 60 i^2 \int_0^\pi \frac{\cos^2\left(\frac{\pi}{2}\cos\theta\right)\sin^2\left[\frac{\pi n}{2}(1-\cos\theta)\right]d\theta}{\sin\theta\,\sin^2\left[\frac{\pi}{2}(1-\cos\theta)\right]} \quad (37)$$

when n is even

$$P = 60 i^2 \int_0^\pi \frac{\sin^2\left(\frac{\pi n}{2}\cos\theta\right)}{\sin\theta}\,d\theta \quad (38a)$$

when n is odd

$$P = 60 i^2 \int_0^\pi \frac{\cos^2\left(\frac{\pi n}{2}\cos\theta\right)d\theta}{\sin\theta} \quad (38b)$$

With the aid of Van Der Pol's solution we obtain

$$P = 30 n i^2\left[E + \log_e 2\pi n - Ci(2\pi n)\right] \quad (39)$$

Where Ci, as before, is the integral cosine, the value of which is not far from zero. The following table gives the values of the resistance for various values of n.

1	2	3	4	5	6	7	8
72.5	47	30.2	22.5	24.8	21.1	27.3	16.00

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e.) Certain more complicated combinations may be reduced to the discussed typical cases; thus, for example, a combination of stacked antennae with a horizontal base line, as well as "space systems", which consist of a number of radiators, may be so reduced. The rule for compounding the formula is the same and it may be expressed as follows:

$$P = \frac{60 i^2}{\pi} \int_0^{\pi} \int_0^{\pi} \frac{\cos^2\left(\frac{\pi}{2}\cos\theta\right)}{\sin\theta} \cdot y_1 y_2 y_3 \ldots dx \cdot d\theta \qquad (30)$$

II. Distribution of Radiation in Space.

The regions of darkness are distributed, as has already been said, along the arcs of small circles of the sphere which surrounds the antenna. These arcs satisfy the condition $Y_K = 0$ where Y_K is a phase factor occurring in expression (30). For single stack antennae the projections of these circles on the equatorial plane are straight lines aa, bb (Fig. 8). These straight lines are parallel to the projection of the main meridian. In the case of an in-phase system of radiators, the main ray is marked out by zones a. The space occupied by said ray may be obtained by rotating sector a_0Oa_0 around O.

In the case of a system with alternating phases (harmonic) the main ray is limited by zone b. The space occupied by this ray may be obtained by rotating sector O_0ON_1 around axis ON_1 and thus the shape of a cone. Here is apparent the noteworthy difference between the radiation distribution due to the two systems. This difference becomes apparent when the radiation distribution along the equatorial plane is compared with that along the arc of any small circle. The projections of the latter are indicated in Fig. 8 by dotted lines. It is easily seen that as the small circle approaches the v/43

zenith the side rays successively diminish. In the region nearer the zenith there remains only the main ray which itself finally practically disappears at some definite angle of altitude in a given in-phase system. Conversely, in case of an antenna with alternating phases, as the altitude above the horizon increases the main ray disappears first and is followed by side rays in succession. In case of multi-stacked antennae the projections of the zones of zero radiation (darkness) are represented by concentric circles whose common center coincides with the center of the equatorial plane (Fig. 9). By combining the two types of radiators into a single system a space antenna is obtained which may have several stories. In this case the projections of regions of darkness on the equatorial plane have the appearance of a net (Fig. 10). The radiation of a system as this consists of a large number of individual rays of different intensities and shapes separated by mutually intersecting zones of darkness.

II. The Mirror.

a.) The action of an unlimited conducting mirror may be replaced by the action of the images of the real antennae. For radio frequency waves the surfaces of the earth is more like a surface of a scattering medium. The reflection depends upon the wave length, upon the angle of incidence of the ray and, very probably, on the amplitude of the electromagnetic field. In the first approximation one may regard the earth as a metallic mirror. This is confirmed by experiments in case of reflection of waves or order two meters from soils moistened with water of small salt content. In what follows the surface of the earth will be considered to be flat and possessing an absorption coefficient K. By the absorption coefficient will be meant the ratio of the

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absorbed to the incident energies.

Let us consider an antenna with vertical radiators located at the center of a large sphere, the equatorial plane of which coincides with the surface of the earth. Let us first determine the mean square value of the resulting magnetic vector H on the surface of the sphere which is due to vectors h and $h\sqrt{1-K}$ produced by the antenna itself and its image. In order to find the phase function ν the antennae will be replaced by dipoles. The phase difference between the component vectors at a point on the sphere is due, first of all, to phase difference φ produced by the difference of travel of the rays $\varphi = \frac{4\pi l}{\lambda}\cos\theta$. Here l is the distance of the midpoint of the antenna from the surface of the mirror and θ is the polar coordinate of the point. Secondly, the phase difference depends upon the difference in current phases in the dipoles at the center of antennae which must be determined in accordance with formula (7). Because the phase of each such dipole with respect to the first element of the antenna is equal to $\Delta = \gamma + \zeta\frac{(n-1)}{2}$ the phase difference $\Delta_1 - \Delta_2 = \gamma_1 - \gamma_2$ where γ is the phase of the first element. In cases of in-phase antennae (Fig. 11) it is clear that $\gamma_1 - \gamma_2 = 0$. In the case of an antenna with alternating phase (Fig. 12) we have

$$\gamma_1 - \gamma_2 = \pi(n-1)$$

Accordingly, the root mean square value is

$$H^2 = h^2\left[2 - K + 2\sqrt{1-K}\cos\left(\gamma_1 - \gamma_2 + \frac{4\pi l}{\lambda}\cos\theta\right)\right] \quad (31)$$

The square of the phase function including the corrections due to the loss of energy at reflection is easily seen to be $\psi_1^2 = \frac{H^2}{h^2}$

When for a given antenna system, when it is removed to a considerable distance

from the earth, the radiated power is given by

$$P_1 = A\int_0^{2\pi}\int_0^{\pi} f(\alpha, \theta)\, d\alpha\, d\theta \tag{32}$$

Then the mirror action of the earth results in the following power

$$P_2 = A\int_0^{2\pi}\int_0^{\frac{\pi}{2}} f(\alpha, \theta)\, \psi_1^2\, d\alpha\, d\theta \tag{33}$$

and the total power radiated by the antenna is

$$P_3 = \frac{P_2}{1-\frac{\chi}{2}} \tag{34}$$

In this fashion the antenna resistance in the presence of the earth may be found.

The presence of factor 42 in the integrand produces new zones of reduced radiation which lie in the planes of small circles defined by the following equation:

$$\cos\left[\frac{4\pi \ell}{\lambda}\cos\theta - \gamma_1 - \gamma_2\right] = -1 \tag{35}$$

In order that complete darkness may be produced it is necessary that $\chi = 0$. The number of these zones increases with ℓ.

If K is put equal to zero and $\ell = \frac{\lambda n}{4}$ and if the phase function ψ_1 is introduced into the equation, for the alternating phase antenna, the formulas of Ballantine and Van der Pol are obtained in the following form

For even n

$$P = 60 i^2 \int_0^{\frac{\pi}{2}} \frac{[1-\cos(\pi n \cos\theta)]^2}{\sin\theta}\, d\theta, \tag{36}$$

For odd n.

$$P = 60 i^2 \int_0^{\frac{\pi}{2}} \frac{[1+\cos(\pi n \cos\theta)]^2}{\sin\theta}\, d\theta$$

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b) Let us consider an antenna system with vertical radiators located at the center of the usual large sphere and let there be an unlimited periodic mirror parallel to the axis of the oscillators and to their base line SS_1. In the equatorial plane on the surface of this sphere the phase displacement between the vectors due to the antenna and those due to its image is

$$\varphi = + \cdot \frac{4\pi l}{\lambda} \cos\alpha + \gamma_1 - \gamma_2$$

where l is the distance of the mirror surface from the geometric mid-point of the antenna, and $\gamma_1 \quad \gamma_2 = \pi$ (Figs. 13 and 14).

If this expression is extended to apply the complete sphere the phase function is found to have the following form

$$V_2^2 = \left[2 - \kappa - 2\sqrt{1-\kappa} \quad \cos\frac{4\pi l}{\lambda}\cos\alpha\sin\theta \right] \quad (37)$$

The intersections of zones of darkness with the equatorial circle are determined by the condition

$$\cos\frac{4\pi l}{\lambda}\cos\alpha = +1 \quad (38)$$

The planes of these zones of darkness are parallel to the plane of the mirror and in the case in question are at right angles to the main meridian circle.

c) The mirror action of the earth in the case of an inclined antenna is of great interest. V/97

The analytical study of this case is very complicated and we shall limit ourselves to the following observations. The law $h_0 = f(\alpha, \theta)$ for the amplitude of the magnetic vector which is produced on the sphere by the antenna is assumed to be known when the axis of the sphere is parallel to the axis of the radiator. In case of a sphere, the polar axis of which makes an angle ε with the axis of the radiator, we have $h_0 = f(\beta, \Delta)$ where β and Δ are the new variables, connected with the old variables by known relations obtainable from the rotation of the polar axis. When the plane of the mirror coincides with the equatorial plane of the new coordinate system the axis of the radiators in the image make angle $\pi - \varepsilon$ with the new polar axis.

The amplitude of the magnetic vector which is produced by the image is expressed as follows:

$$h_0' = \sqrt{1-K}\; f[(\pi - \Delta), \beta]$$

that is, it differs from the corresponding expression for the antenna itself.

When the phases of the two vectors coincide, the amplitude of the resultant vector is a geometrical sum of the components with an angle ε included between them. In fact, such a coincidence of phases occurs only at certain points on the sphere so that, in general, there exists a phase difference which is due to the difference in path. In such cases it is possible to obtain the resultant vector in the following manner

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Let $h_0 \sin(\omega t)$ (Fig. 18) be the vector due to the antenna and let $h_0^1 \sin(\omega t+\varphi)$ be that due to the image; both at a given point on the sphere. Suppose that the directions of the two vectors make angle ζ with each other. Let the axis ox of the rectangular coordinates coincide with the directions of h_0 then the projections of the resultant vector H on the x and y axes are

$$H_x \sin z = h_0 \sin \omega t + h_0' \sin(\omega t + \varphi) \cos \zeta \quad (39)$$

$$H_y \sin z_1 = h_0' \sin(\omega t + \varphi) \sin \zeta \quad (40)$$

Hence

$$H_x^2 = h_0^2 + (h_0' \cos \zeta)^2 + (h_0' \cos \zeta)^2 + 2 h_0 h_0' \cos \zeta \cos \varphi \quad (41)$$

$$H_y^2 = (h_0' \sin \zeta)^2 \quad (42)$$

Since H_x and H_y are at right angles to each other the Pointing Vectors for each component may be calculated separately and the sum of these will represent the resultant vector. The cooperation of H_x and H_y produces a rotating field when ζ is not equal to $K\pi$ and $\varphi \neq K\pi$ (K is the whole number).

In this case the phase function cannot be written out for h_0 and h_0^1 vary in accordance with two different laws. The distribution of regions of darkness due to the antenna and its image depend on whether the antennae alone or their base lines as well are inclined. 4/51

In the latter case, the interference phenomena acquire even more complicated character and the coincidence of zones of darkness of the antennas and of those of the mirror is increased In this case, there exists only a diminution of radiation at the intersection of zones due to the antennas and the mirror. In that manner the inclination of the antennas with respect to the mirror does away with interference bands and consequently acts in a favorable manner in regard to the phenomena of fading.

Fig. 16 represents the projection of the radiation picture of an in-phase system with elevated horizontal Lecher wires. The plane of the system is inclined. The antenna and its image have common zones of darkness. The main Ray is inclined to the earth at the same angle as the inclination of the antennas. By means of dotted circles with the center at the pole, are represented the zones which correspond to the zones of darkness produced by the interference of radiation from the antenna and its image. In this case, however, there are no zones of darkness but regions in which the magnetic vectors from the antennas and the image meet in opposite phase. This does not bring about darkness since the laws of variation will differ for the two vectors and a space angle exists between them.

Fig. 17 relates to the same antenna with an inclined Lecher system. The radiators are arranged in a plane perpendicular to the earth. On the sphere are two independent mutually intersecting systems of zones of darkness. The full lines indicating the zones due to the antennas while the dotted lines indicate the zones due to the image. A complete darkness can occur only at points at which both systems coincide. A similar

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terference picture occurs in case of an inclined wire with alternating phases.

d) A tuned mirror may be excited or energized by means of special couplings with the antenna. In case when excitation is produced by driving, it is possible to vary the amplitude and the phase of the mirror in any manner whatever.

Let a vertical radiator of length $\lambda/2$ be placed in the center of the large sphere and let there be at a distance ℓ and parallel to it a mirror B of the same length. The relation of the current in the mirror to that in the radiator is given by

$$\lambda = F(\ell)$$

The displacement of phase between the magnetic vectors A and B in the equitorial plane is equal to the sum of the following quantities:

1. The loss of phase along the path A-B, that is

$$\frac{2\pi\ell}{\lambda}$$

2. The phase displacement produced by the difference in phase (ℓ) between the fields which arrive at the mirror and which are produced by the mirror itself.

3. The phase difference which is due to the difference in path

$$\frac{2\pi\ell}{\lambda}\cos\alpha$$

The first two terms have the same values for all points on the sphere, the last may be given for different points on the surface in the V/53

following manner:

$$\frac{2\pi l}{\lambda}\cos\alpha\sin\theta$$

If the mean square value of the resulting vector on the sphere is (H) and the components are h and nh then

$$\psi_3^2 = \frac{H^2}{h^2} - 1 + N^2 + 2N\cos\left[\zeta + \frac{2\pi l}{\lambda}(1+\sin\theta\cos\alpha)\right] \quad (4?)$$

The value of ψ_3^2 varies in accordance with the argument of the cosine and remains between the limits. $(1+N)^2$ and $(1-N)^2$. When $N=1$ the maximum value of $\psi^2 = 4$ and the minimum value is zero. When N is approximately unity and (ζ) is near π one finds for the equatorial plane the following. When the mirror is close to the antenna ($l=0$) $\psi_3^2 = 0$ for every value of azimuth. When $l = \frac{\lambda}{4}$; then $\psi_3^2 = 4$ for $\alpha = \frac{\pi}{2}$ and $\psi_3^2 = 0$ for $\alpha = -\frac{\pi}{2}$

The radiation directed toward the antenna. When (l) increases still farther the ray divides itself into two parts which spread out more and more on opposite sides. In the case when $\frac{l}{\lambda} = \frac{1}{3}$ the radiation diagram has a butterfly-like appearance and the two larger wings are directed towards the antenna. At the maximum when $\alpha = \frac{\pi}{4}$ and $\frac{3}{4}\pi$ $\psi_2^2 = 4$ When $l = \frac{\lambda}{2}$, $\psi_3^2 = 4$ and the radiation is directed at right angles to the line joining the antenna and its image. When the mirror is excited by induction from the antenna $N<1$ and N increases as the mirror approaches the antenna. From experience

it has been found that the best direction of the ray is obtained when the $l < \frac{\lambda}{4}$.

It has been shown by W. W. Tatarinaw that the best distance is $l = .20\lambda$

When there is no forced excitation the phase function may be applied to complicated antennas only when the distance between the radiator and its mirror is considerably smaller than the distance to the nearest neighboring radiator. In this case the mirror may be assumed to be coupled only to one of the radiators.

When the mirror system is at distance $.20\lambda$ this condition is approximately fulfilled.

c) The resistance of an antenna in the presence of a mirror may be determined by obtaining the corresponding integral in which the integrand is multiplied by the phase function of the mirror. For example, in the case of a long/vertical conductor with alternating phases the power is obtained in accordance with the equation (34)

$$P_3 = \frac{P_2}{1-\frac{K}{2}}$$

where P_2 is the reflected power. In accordance with equations (26) and (31) this power may be expressed in the following manner:

$$P_2 = 60 i^2 \int_0^{\frac{\pi}{2}} \frac{\cos^2\left(\frac{\pi}{2}\cos\theta\right) \sin^2\left[\frac{\pi n}{2}(1-\cos\theta)\right]\left[2-K+(-1)^{n+1} 2\sqrt{1-K}\cos\left(\frac{4\pi l}{\lambda}\cos\theta\right)\right]}{\sin\theta \cdot \sin^2\left[\frac{\pi}{2}(1-\cos\theta)\right]} d\theta \quad (44)$$

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The calculation of this integral yield the following

$$P_\Sigma = P_1 + (-1)^{n+1} \cdot 15 i^2 \frac{\sqrt{1-k^2}}{1-\frac{k}{2}} \Big[\sin(p\pi) \Big\{ 2 Si(2p\pi) - Si(2\pi(p-n)) - Si(2\pi(p+n)) \Big\} - \cos(p\pi) \Big\{ 2 \lg(2\pi p) - 2Ci(2\pi p) - \lg(2\pi(p-n)) - \lg(2\pi(p+n)) + Ci(2\pi(p+n)) + Ci(2\pi(p-n)) \Big\} \Big] \tag{48}$$

where P_Σ is the radiated power in the absence of the mirror, and is determinable by equation ([illegible]). K is the absorption coefficient and n is the number of half-waves in the conductor, P is the distance of the mid-point of the conductor from the mirror in terms of quarter wave-lengths. Si the integral sine; Ci the integral cosine, and Lg the natural logarithm.

When $p = \frac{4l}{\lambda}$ is a whole number, the first term in the brackets is equal to zero because $\sin p\pi = 0$

in the second term all the integral cosines will be approximately zero with the exception of the case when $p = a$

then

$$Ci(p-a) - \lg(p-a) = E = .577 \tag{49}$$

When P is a whole number the shortest distance between the antenna and its image is a whole number of half wave lengths. When 2P is a whole odd number

$$\cos(p\pi) = 0$$

and consequently there remains only the first term in the square brackets. This corresponds to the case where the nearest point on the antennae is an integral number of quarter wave lengths from the image. In Figs. 18 and 19

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are shown curves which were constructed in accordance with formula (45) for the case when the earth is regarded as having $K = 0$. The ordinates represent the increase in the radiation resistance of a half-wave length due to the influence of the earth. Through similar substitutions into equation (20) and calculations of therein contained integrals the following expressions are found for a system of in-phase vertical conductors:

$$P_3 = P_1 + 15 i^2 \frac{\sqrt{1-R}}{1-\frac{R}{2}} (-1)^{n+1} \left[\overset{n\pi}{\underset{0}{S}} - 4 \overset{(n-1)\pi}{\underset{0}{S}} + 8 \overset{(n-2)\pi}{\underset{0}{S}} - \right. \tag{47}$$

$$\left. - 12 \overset{(n-3)\pi}{\underset{0}{S}} + \qquad \pm (n-1) 4 \overset{\pi}{\underset{0}{S}} \right]$$

Where the abbreviations $\overset{a\pi}{\underset{0}{S}}$ is given by the following formula:

$$\overset{a\pi}{\underset{0}{S}} = \sin(p\pi) \left[2 \operatorname{Si}(2p\pi) - \operatorname{Si}(2\pi(p-a)) - \operatorname{Si}(2\pi(p+a)) \right] -$$

$$- \cos(p\pi) \left[2 \lg(2\pi p) - \lg 2\pi(p-a)) - \lg(2\pi(p+a)) \right.$$

$$\left. + 2 \operatorname{Ci}(2\pi p) - \operatorname{Ci}(2\pi(p+a)) - \operatorname{Ci}(2\pi(p-a)) \right]$$

Where the letters have the same meaning as in equation (45). Calculations may be carried through by successive substitutions of values of $\overset{a\pi}{\underset{0}{S}}$ for $a = n,\ n-1,\ n-2,$

into equation 47. When $p = \frac{4l}{\lambda}$ [redacted] is a while number, the first term in (48) is equal to zero and all integral cosines in the second term are nearly zero with the exception of the case $a = p$ when

$$\operatorname{Ci}(2\pi(p-a)) - \lg(2\pi(p-a)) = E = .577 \qquad \text{V/57}$$

When 2N is an odd number, the second term is equal to zero. An investigation of equation (45) and (47) shows that the mirror near an antenna produces a considerable effect on the resistance of the antenna. Depending upon the distance between the antenna and the mirror, the radiator may bring about either an increase or a decrease of resistance.

When the lower end of a vertical conductor is located near the soil of high conductivity, a very small displacement of the conductor produces large changes in resistance.

f). In an important practical case when the mirror is located behind a flat in-phase directional antenna from which the radiation is directed to one side, the calculation of resistance is greatly simplified if it is assumed that the mirror does not influence the distribution of energy in the ray but merely rotates a half of it 180°. This, in the first approximation, is allowable only when the number of radiators is not too small.

Then in the previously derived formula (43)

$$\psi_3^2 = 1 + N^2 + 2N\cos\left[\zeta + \frac{2\pi l}{\lambda}(1 - \sin\theta\cos\alpha)\right] \qquad (43)$$

one may put $\sin\theta\cos\alpha = \cos\alpha_1$ equal to unity, Since α_1 is small in the equatorial plane. Thus we have

$$\psi_4^2 = 1 + N^2 + 2N\cos\left(\zeta + \frac{4\pi l}{\lambda}\right) \qquad (49)$$

and consequently

$$\Gamma_3 - \frac{2P_2}{1+\bar{N}^2} = \frac{2P_1}{1+\bar{N}^2}\left[1 + N^2 + 2N\cos\zeta + \frac{4\pi l}{\lambda})\right] \qquad (50)$$

Formulas (45), (47) and (50) may be used for experimental determinations of the absorption co-efficients.

"Nijni-Novgorod, Radiolaboratorium, April 28, 1926."

(Received June 11, 1926). V/59

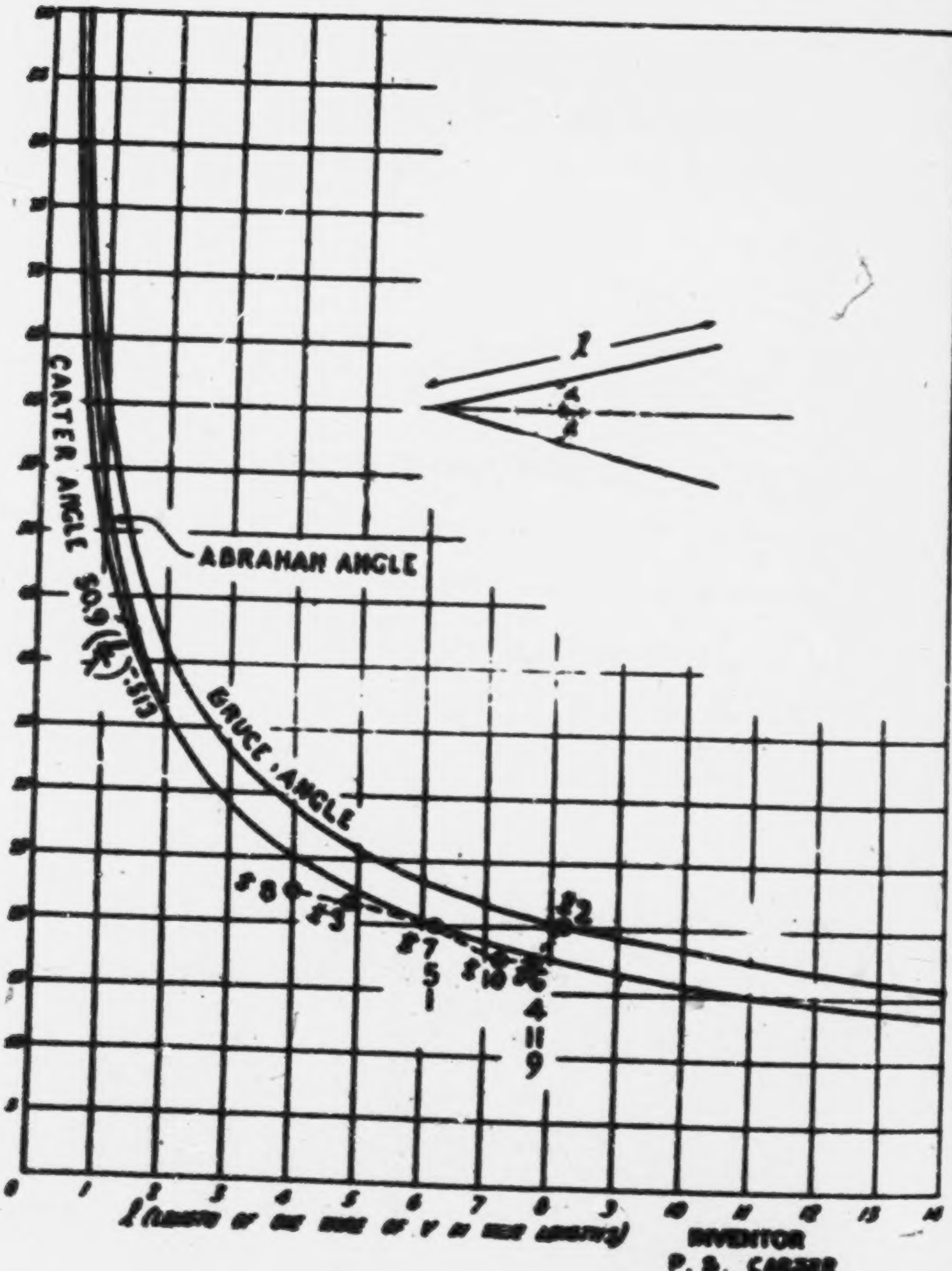
DEFENDANT'S EXHIBIT W

Sept. 18, 1934. P. S. CARTER 1,974,387

ANTENNA

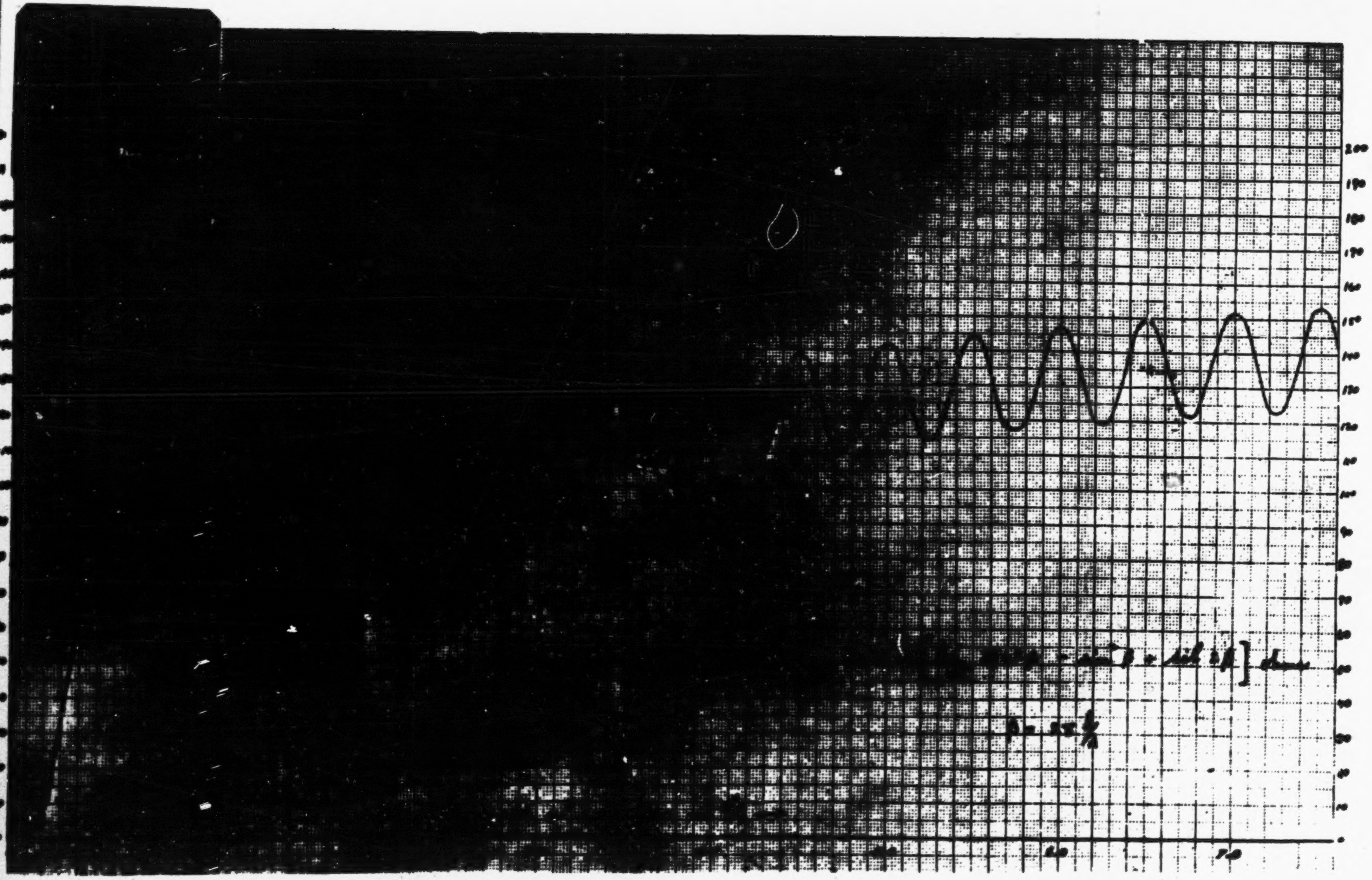
Filed June 11, 1930 4 Sheets-Sheet 4

Fig. 12



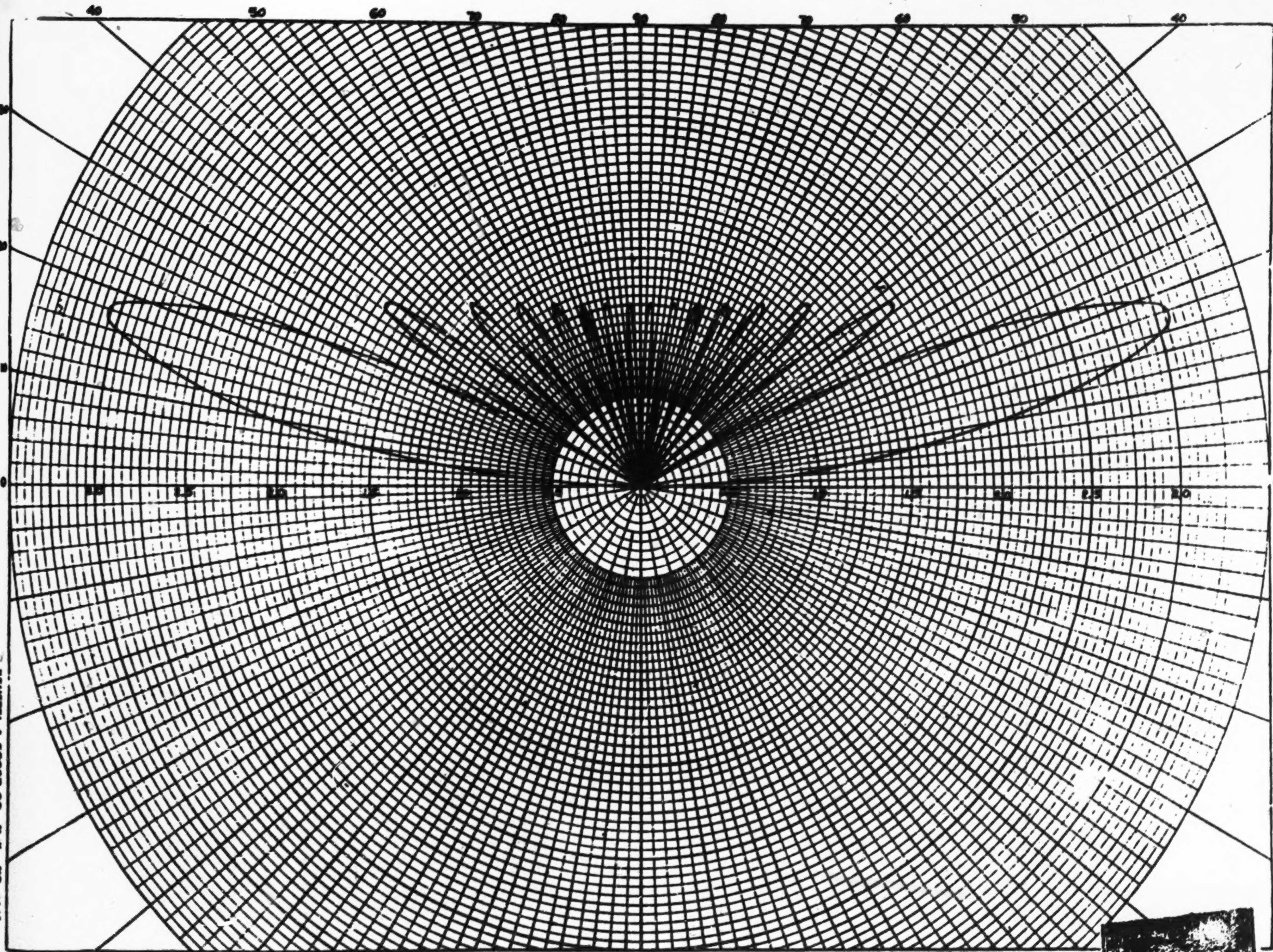
INVENTOR
P. S. CARTER
BY H. G. Grover
ATTORNEY

DEFENDANT'S EXHIBIT X



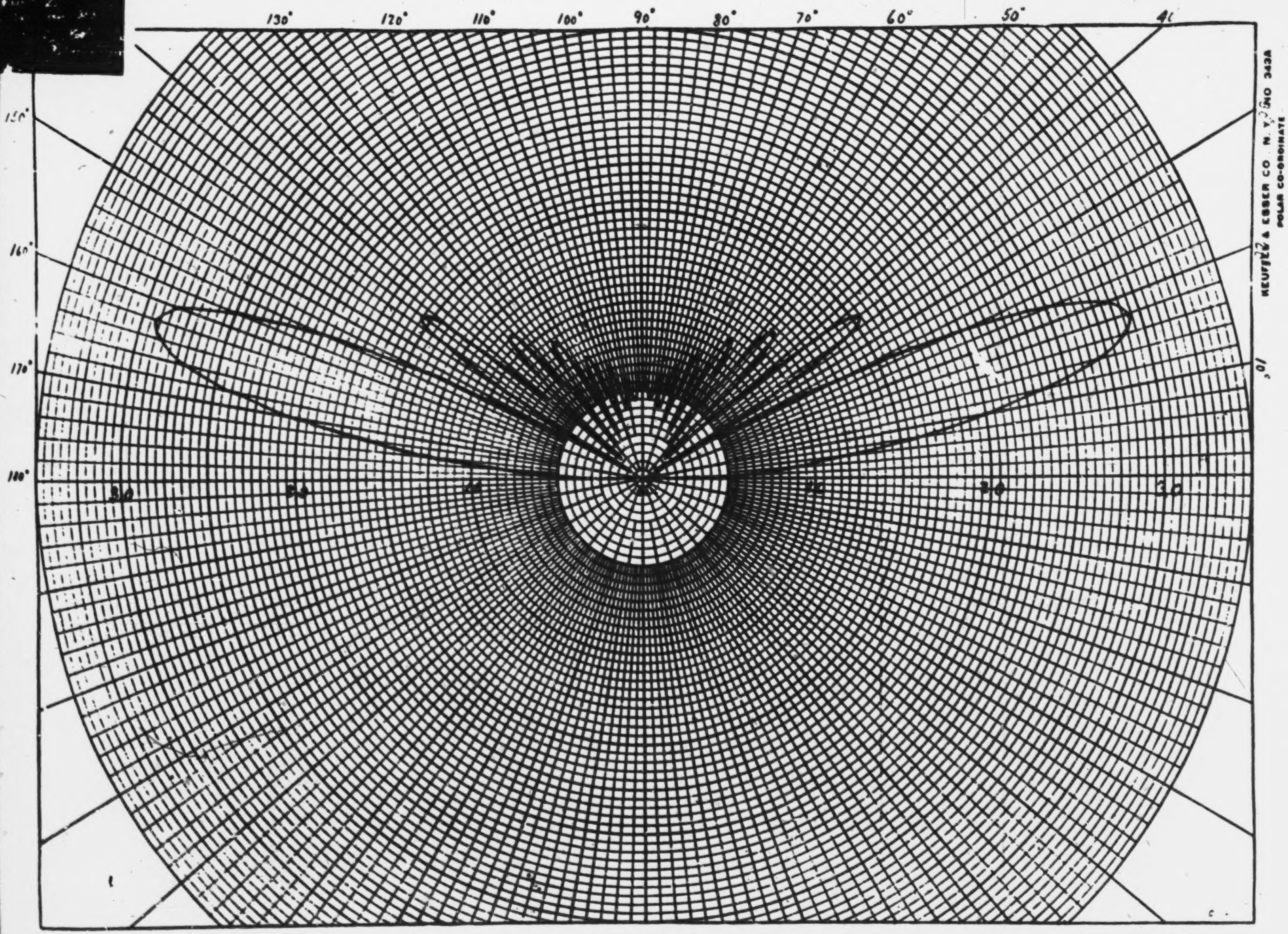
DEFENDANT'S EXHIBIT Y 1025

RADIATION OF 8 WAVELENGTH STRAIGHT WIRE



DEFENDANT'S EXHIBIT Z
1026

Radiation of 7¾ Wavelength Straight Wire



824 1027

DEFENDANT'S EXHIBIT AA

TRANSLATION.

FRENCH PATENT NO. 596,737

JOSEPH BETHENOD

SYSTEM OF AERIALS FOR THE TRANSMISSION OF SHORT WAVE WIRELESS TELEGRAPH SIGNALS.

Application filed July 11, 1924; patent issued August 14, 1925; published October 30, 1925.
(Patent whose issuance has been postponed pursuant to Article 11, paragraph 7 of the Law of July 5, 1844, amended by the Law of April 7, 1902.)

The present invention is based on the following experimental data:

It is known that an excellent sending antenna for medium or long waves may be constituted by a horizontal network of wires which are suspended from poles which are as high as possible. This will form the aerial proper and is connected through a suitable down-lead with one pole of the high frequency source which is provided on the ground. The other pole of this source is connected with a second horizontal network provided below the first at a slight distance above the ground, and forms what is called the counterpoise or screen. The fundamental wave length of such system is generally lower than the transmission wave length.

A similar arrangement may be provided for the emission of short waves and, in that case, the antenna thus constituted may be operated at the harmonics. However, in accordance with the arrangements forming the object of the present invention, it is important that the high poles be retained if it is desired that the antenna function in accordance with its fundamental wave. As a matter of fact, calculations and experiment show that with short waves the

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higher the elevation of the counterpoise above the ground, the greater the advantages that may be derived therefrom. This consideration will lead one to the arrangement shown in Fig. 1 to exemplify the invention.

The poles 1-1 support the horizontal network 2 as high as possible. Under the network 2 is provided at 3, the counterpoise above referred to, insulators 4 being inserted in the suspension cables. In accordance with one of the characteristics of the invention, the height of 3 above ground 8 may be greater than the vertical distance between 2 and 3. It should be understood, of course, that, as well known, the screen 3 may cover a larger surface than the network. The feeder 5 of the network may be arranged in many ways, and particularly it may comprise either a single wire or a plurality of parallel wires. Furthermore, the portion of the down-lead 5 which is below the counterpoise 3 may be arranged in a different manner. It may constitute, with the conductor 6, which connects the counterpoise with the high frequency source M, F, a real double wire energy transmission line which has suitable characteristics, etc.

Fig. 2 exemplifies another solution in which relatively high poles 1 are used. The oscillator proper consists of a wire (or system of wires) 9 excited in any suitable manner from a high frequency source (not shown). In order to obtain a directional effect a series of vertical wires 10 forming a mirror are arranged in the well known manner along a parabolic base. These wires constitute a corresponding number of oscillators which are inductively excited and which are preferably tuned to the local oscillator 9. The latter may, as well known, be eliminated, provided that the oscillators 10 AH/t

be respectively fed with currents which are suitably phased with respect to one another, etc.

Obviously, numerous other variants are possible. Particularly the two networks 2 and 3 of Fig. 1 may be arranged vertically or even inclined not only with respect to the ground, but also with respect to one another so as to obtain directional effects either in the horizontal plane, or in the vertical plane, or in both planes. Furthermore, as well known, the antenna may in all cases be, if necessary, excited at its harmonics.

Finally, the high frequency source itself may be arranged at a great height above the ground, e.g., at an intermediate platform on one of the poles. This arrangement would be particularly suitable for triode type generators, the current supply of the triodes being provided on the ground and connected with the high frequency apparatus through suitable cables.

R E S U M E

Antenna system for emitting short wave wireless telegraph signals, characterised by the provision of the oscillator at a relatively high point above the ground.

AWB

N° 596.737 M. Bethenod Pl. unique

Fig. 1

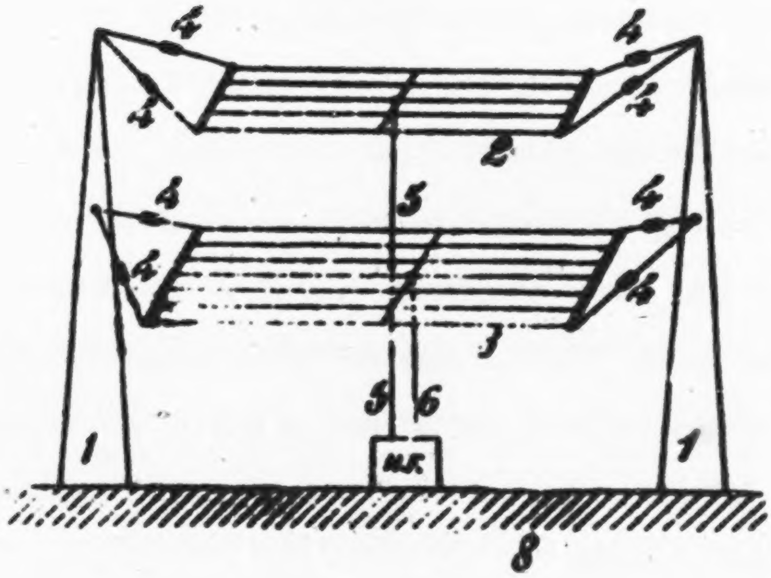
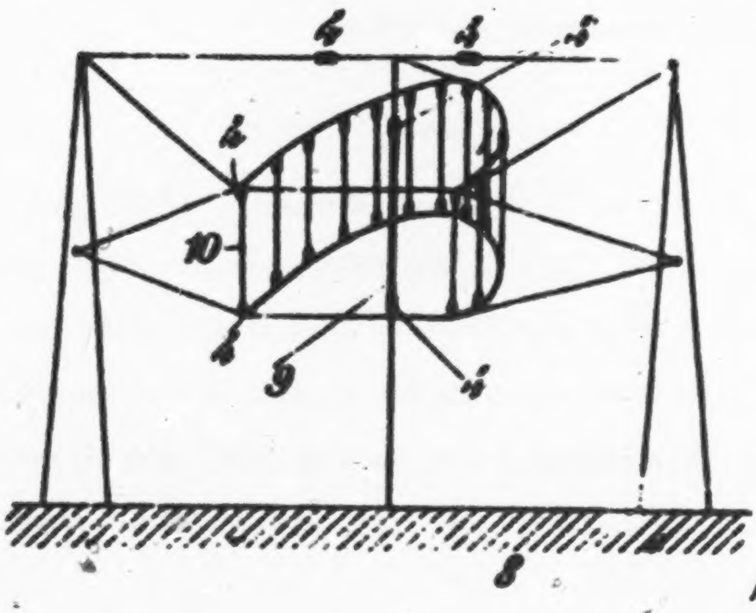


Fig. 2



AR/4

TRANSLATION -

FRENCH PATENT No. 625,896

JOSEPH BETHENOD

ANTENNA ARRANGEMENT FOR SHORT WAVES

Application filed March 9, 1926; issued April 25, 1927; published August 6, 1927.

The object of the present invention is an antenna arrangement which is particularly advantageous in communicating by means of short waves.

Better radiation output is obtained by suppressing losses in that portion of the antenna which is adjacent the station. Mechanical means permit that if required my antenna system may be used for waves of different lengths.

The invention will be better understood with reference to the enclosed drawing and the corresponding description which exemplify without limiting it one elementary embodiment of the invention.

The antenna consists of the conductors A, B, C, grounded at a. This antenna is excited by means of a high frequency current generator in any well known manner, e.g., by means of magnetic coupling with an inductance D connected in series with the antenna.

The portion A,B of the antenna included in the station or located in its immediate neighborhood is, in accordance with the present invention, provided with a screen E.F which may be a simple conductor identical with the portion A,B which we are considering, arranged parallel and sufficiently near thereto. In order completely to simulate said portion the screen E.F may comprise an inductance G, the inductances G and D being adjustable if desired. The screen E.F is connected to ground at E.

The portion B,C of the antenna may form an angle α of any value from 0 to 90° with the horizontal. The antenna is attached at C to an insulator H which

AN/S

in turn is attached to a tensioning rope I. In order to obtain the greatest radiation efficiency for the antenna the length of B,C should preferably be equal to a whole number of half wave lengths. If the installation must operate on a plurality of different wave lengths then, in accordance with the present invention, the length of the portion B,C is made adjustable to the desired length, e.g., in the following manner:

The tensioning rope I passes over a pulley J and carries at its free end a counter-weight K which keeps it tensioned. The antenna conductor passes over a pulley L at B and its lower end is wound on a drum M which may be rotated by means of a handle N through an insulating sleeve O, or by any other equivalent arrangement. It will be understood that the continuity of the electric antenna circuit is insured by the provision of a system of movable connections, e.g., a wiper arrangement P which engages a ring carried by the drum, the wiper P being connected with the inductance D.

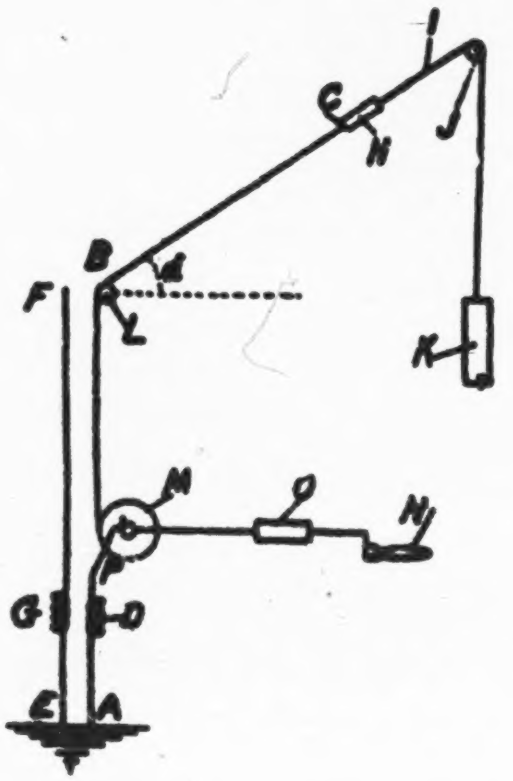
It should be noted that the invention may be subjected to many variations or modifications as far as the details are concerned; a plurality of antenna arrangements of the same type may be combined at the same station and suitably oriented with respect to one another in order to obtain directional effects or to make possible multiplex operation; the antenna and its screen may be interconnected at the points E and A without necessarily grounding these points; the inductances S and D will generally be coupled, care being taken suitably to direct the turns thereof, etc.

R E S U M E

Antenna arrangement particularly applicable to short waves characterized in that radiation of the portion of the antenna which is near the station is neutralized by means of a screen; in that the radiating portion is inclined at any suitable angle with respect to the horizon and has a length equal to a whole number of half waves; and in that preferably this length is adjustable at will by means of a suitable mechanism.

AAH

N° [illegible] H. Bethenod Pl. unique



[fols. 1035-1038] DEFENDANT'S EXHIBIT AA

831

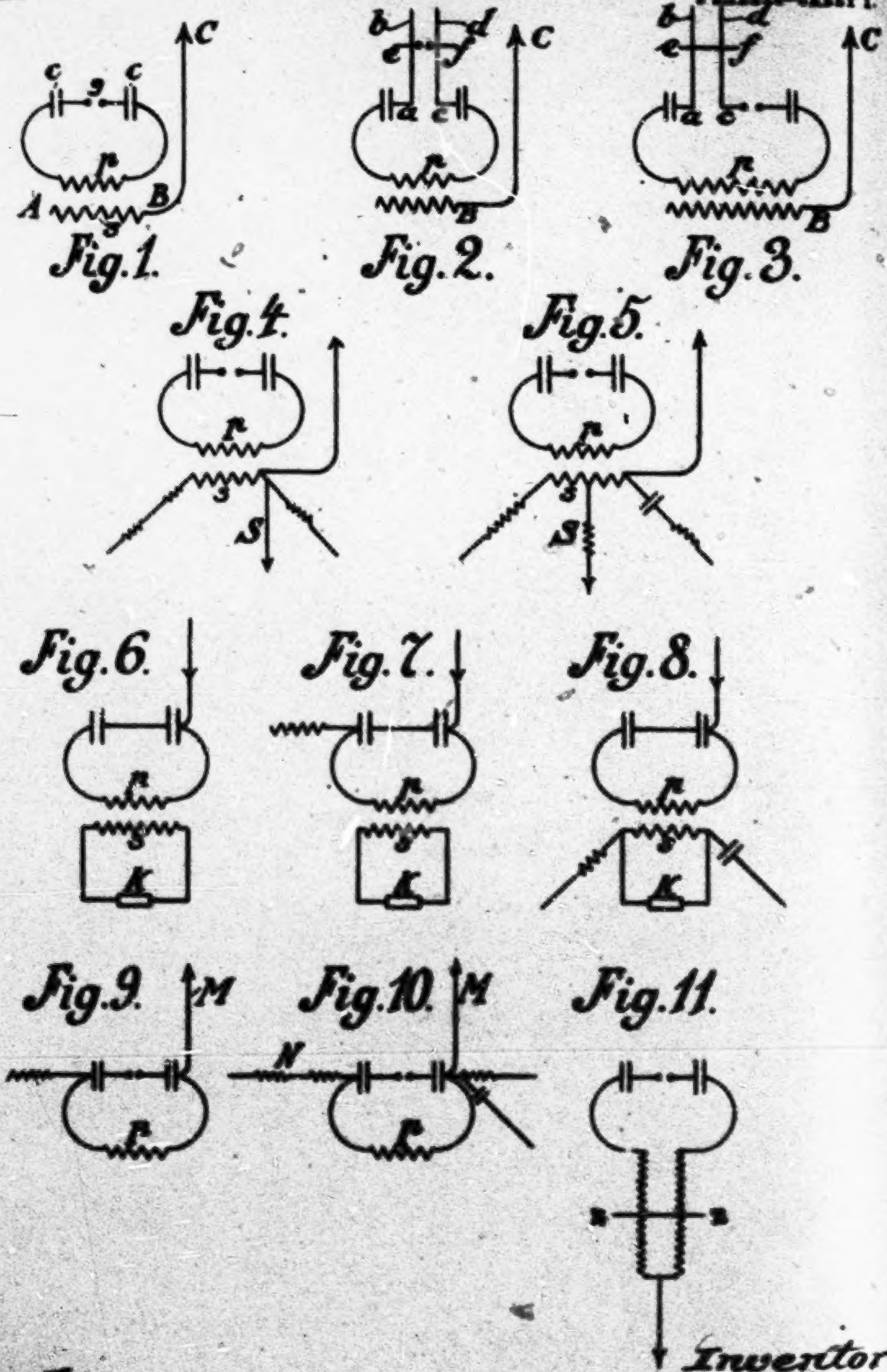
No. 763,345. PATENTED JUNE 21, 1904.

F. BRAUN.

MEANS FOR TUNING AND ADJUSTING ELECTRIC CIRCUITS.

APPLICATION FILED AUG. 8, 1901.

NO MODEL. 2 SHEETS—SHEET 1.



Attest:
T. F. Kehoe
A. M. Dorsey

Inventor
Ferdinand Braun
by
Philipp Sawyer Rice & Kennedy
Attys

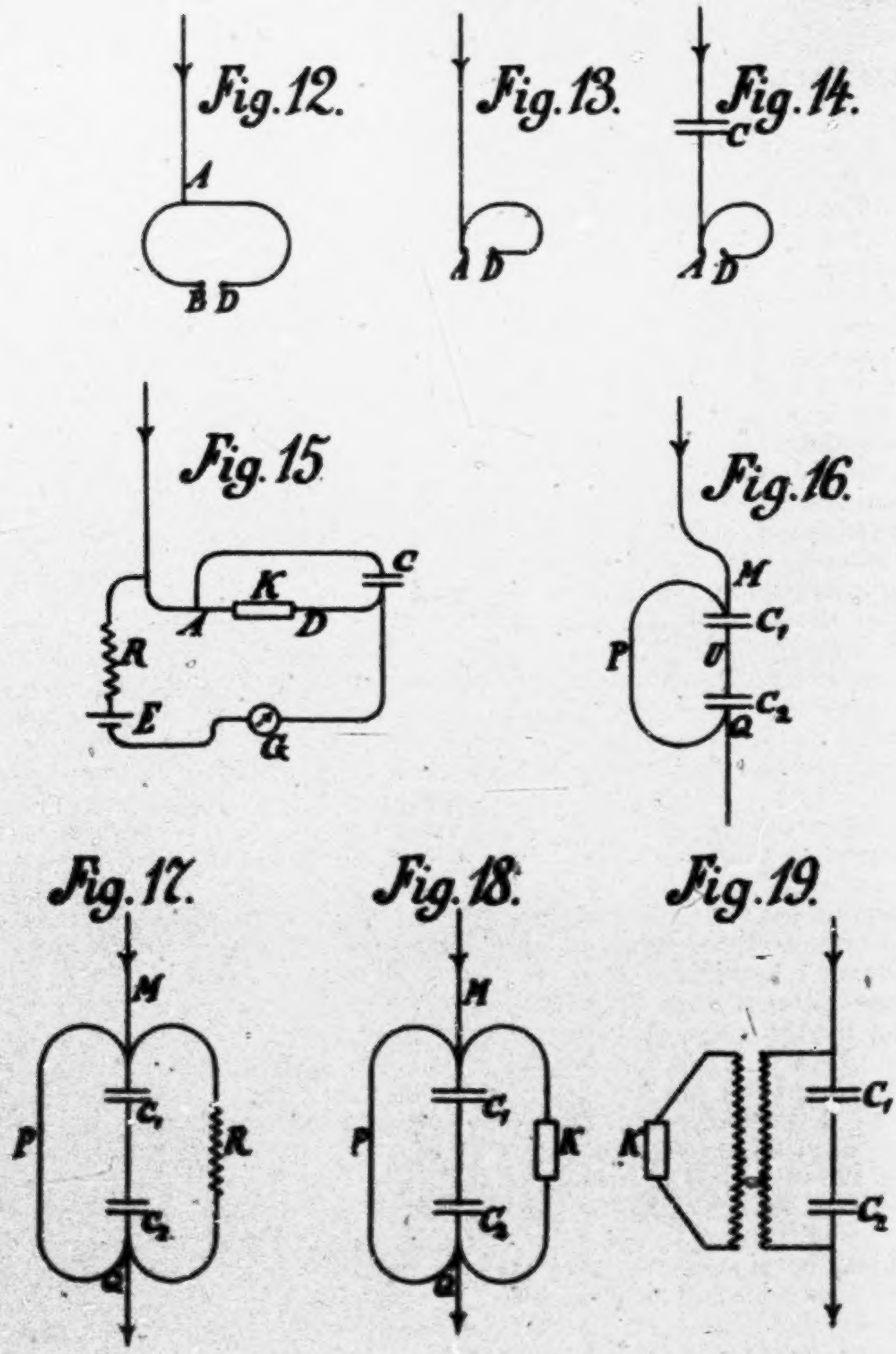
No. 763,345. PATENTED JUNE 21, 1904.

F. BRAUN.

MEANS FOR TUNING AND ADJUSTING ELECTRIC CIRCUITS.

APPLICATION FILED AUG. 8, 1901.

NO MODEL. 2 SHEETS—SHEET 2.



Attest:

Inventor
Ferdinand Braun
by Philipp Sawyer Rice & Kennedy
Attys

No. 763,345. Patented June 21, 1904.

UNITED STATES PATENT OFFICE.

FERDINAND BRAUN, OF STRASBURG, GERMANY.

MEANS FOR TUNING AND ADJUSTING ELECTRIC CIRCUITS.

SPECIFICATION forming part of Letters Patent No. 763,345, dated June 21, 1904.

Application filed August 5, 1901. Serial No. 71,009. (No model.)

To all whom it may concern:

Be it known that I, FERDINAND BRAUN, a subject of the Emperor of Germany, and a resident of Strasburg, Alsace, German Empire, have invented certain new and useful Improvements in Means for Tuning and Adjusting Electric Circuits; and I do hereby declare that the following is a full, clear, and exact description of my invention, which will enable others skilled in the art to which it appertains to make and use the same.

It is known that wireless telegraphy may be made more effective by tuning the electric primary and secondary circuits of the sending and receiving instruments.

The object of the present invention is to improve such tuning.

In accordance with the invention the tuning may be accomplished by adding or inserting certain pieces or coils of wire, the length of which is determined by calculation or experiment.

Apparatus for practicing the invention is illustrated diagrammatically in the accompanying drawings, in which—

Figure 1 shows connections such as are now used for transforming electricity in the transmitter for wireless telegraphy. Figs. 2, 3, 4, and 5 illustrate different ways of modifying such apparatus for the purpose of practicing my invention. Figs. 6, 7, and 8 show the application of the invention to a wireless-telegraph receiver. Figs. 9, 10, and 11 illustrate other applications of the invention to a transmitter. Figs. 12, 13, and 14 illustrate apparatus for practicing the invention by the use of resonators. Fig. 15 shows more fully the electrical connections for a receiver; and Figs. 16, 17, 18, and 19 show other applications of the invention, which will be referred to.

In Fig. 1, which indicates a known form of wireless-telegraphy transmitter, the primary circuit includes the spark-gap g, the condensers cc, and the primary coil p of the transformer. The secondary coil is represented by s, and BC is the transmitting or sending wire. In order to increase the capacity in accordance with my invention, pieces of wire either in straight form or in form of coils are inserted or added—as, for example, as shown in Figs. 2 to 5.

In Fig. 2 the spark-gap is moved from the position ac to the position ef, thereby adding the lengths of wire ab and dc to the circuit.

Fig. 3 shows a modification of the arrangement shown in Fig. 2, in which the spark-gap is removed from the position ac, and the wires ab and dc are connected by a bridge ef, which may be moved in either direction for adjusting the oscillation-circuit, thereby altering the capacity, and consequently the energy. The circuit should be adjusted so that this capacity will be a maximum.

If the transmitter has been given its maximum of capacity by this means, the action may be further increased by adding to the free end A of the secondary coil s additional pieces of wire either in straight or coil form. (See Figs. 4 and 5.) These pieces may advantageously contain induction-coils and condensers, and are characterized by the fact that a certain number of windings give the maximum of capacity, which will be diminished both by increasing or diminishing the number of windings.

Figs. 6, 7, and 8 show the application of the invention to receivers for wireless telegraphy. In Fig. 7 a compensating coil is added to a primary circuit. This connection avoids the necessity of earthing. Fig. 8 shows additional pieces joined to the secondary circuit of the receiver.

Fig. 9 shows an arrangement whereby the symmetry destroyed by the action of the sending-wire M may be restored by adding a compensating coil at the opposite side of the condensers, and Fig. 10 shows a further carrying out of this idea. The coil p, as shown in these figures, acts as an inductance-coil. In certain cases—as, for example, in the practice of wireless telegraphy in connection with moving objects, as ships or balloons—it is preferable to provide adjusting means to avoid asymmetric action, as by means of the bridge zz. (See Fig. 11.) Earth connection may be provided, as shown in this figure.

A preferred form of the additional pieces

is a form of resonator, the nature of which has been discovered by Hertz and his followers. A receiving apparatus employing a resonator is illustrated in Fig. 12. In the apparatus shown in this figure the electric wave passing down the receiving-wire is branched at A in two directions, AB and AD. If now the length of the two wires AB and AD is such that the difference is equal to one-half the length of the waves, the point BD will be in a phase difference of one hundred and eighty degrees. In the resonator a system of waves is produced rising up to a certain maximum. BD are peaks of the waves, so far as electric oscillations are concerned. An earth connection would therefore disturb the condition of resistance and be of no use. For the same reason no capacity is to be added to either of the ends B or D. The most simple arrangement is to make the length AB equal to zero, Fig. 13. Adding capacity, as by condenser C, in the sending-wire will not disturb the effect of the resonator, Fig. 14. The wave generated in the circuit AD is capable of producing induction in any circuit in its neighborhood.

Referring to Fig. 15, K represents a coherer or its equivalent; R, an inductive resistance; E, an element of a battery; G, a galvanometer or its equivalent, and C the condenser.

In using closed oscillation-circuits an arrangement may be employed, as shown in Fig. 16, where the end of the receiving-wire is connected to two condensers C' C², which are joined by the circuit MPQ, the connection between the two condensers being marked U. One condenser may be used instead of two; but the use of two condensers is preferable, for the reason that the necessary adjustment is thereby made easier. The oscillations in closed circuits are much less sensitive to disturbances, and it is possible to add another shunt R (see Fig. 17) without altering the nature of the oscillations.

Figs. 16 and 17 are merely theoretical diagrams, the practical application of the principle shown thereby to a wireless-telegraph receiving system being illustrated in Figs. 18 and 19.

As shown in Fig. 18, the shunt may be used for receiving the coherer or its equivalent. The closed circuit may be used for inducing currents in the secondary circuit, which contains the coherer, as shown by Fig. 19. Conditions will determine whether it is preferable to use a closed or open resonator.

I claim—

1. In wireless telegraphy, the combination with a closed oscillation-circuit, of an added piece of wire for restoring the symmetry disturbed by the sending or receiving wire, substantially as described.

2. In wireless telegraphy, the combination with a closed oscillation-circuit, of an added piece of wire in the form of a coil for restoring the symmetry disturbed by the sending or receiving wire, substantially as described.

3. In wireless telegraphy, the combination with a closed oscillation-circuit, of an added piece of wire and a condenser for restoring the symmetry disturbed by the sending or receiving wire, substantially as described.

4. In wireless telegraphy, the combination with a closed oscillation-circuit, of an added piece of wire in the form of a coil and a condenser for restoring the symmetry disturbed by the sending or receiving wire, substantially as described.

In testimony whereof I have hereunto set my hand in presence of two subscribing witnesses.

FERDINAND BRAUN.

Witnesses:

MARIA SCHORN,

SIEGFRIED BRAUN.

[fols. 1039-1042] DEFENDANT'S EXHIBIT AA

G. REUTHE.

ANTENNA ARRANGEMENT FOR WIRELESS SIGNALING OR THE LIKE.

APPLICATION FILED MAY 25, 1918.

1,314,095. Patented Aug. 26, 1919.

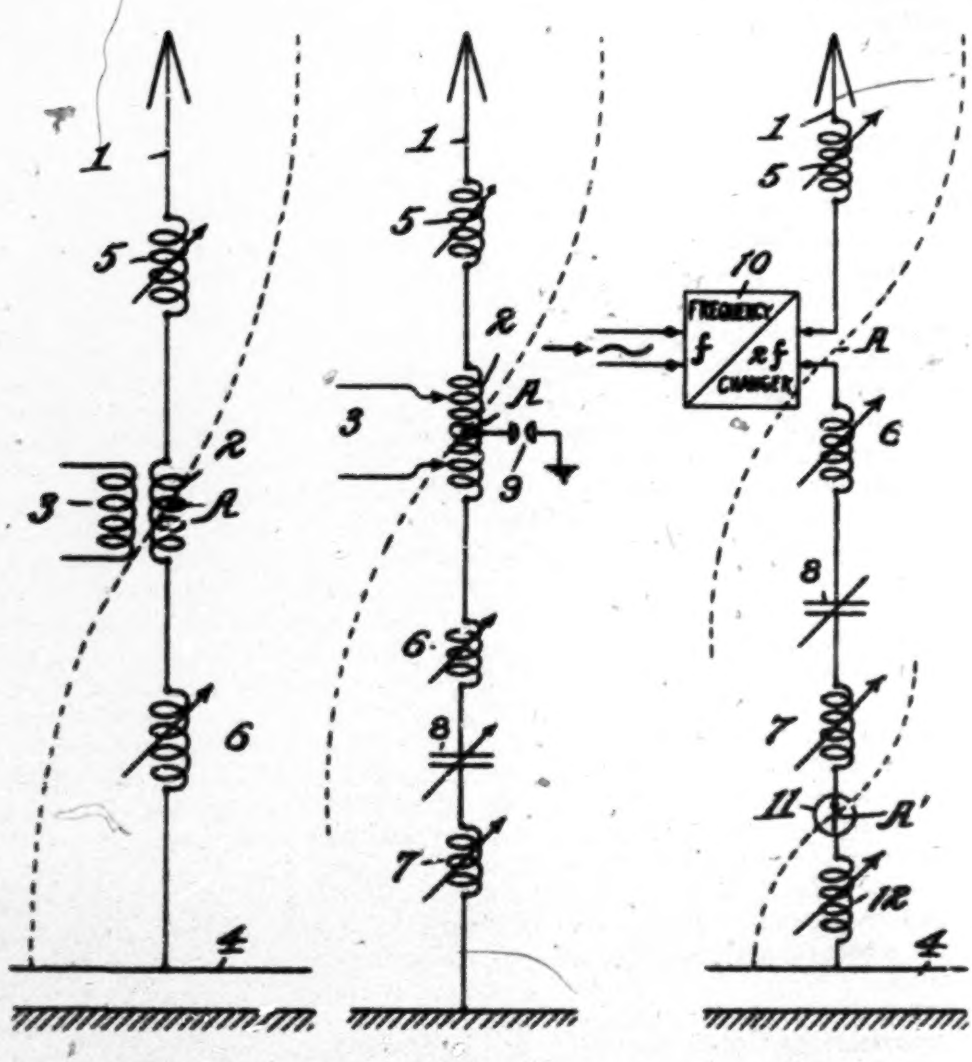


Fig:1. Fig:2. Fig:3.

Gustav Reuthe
Inventor

By his Attorneys

UNITED STATES PATENT OFFICE.

GUSTAV REUTHE, OF SAYVILLE, NEW YORK.

ANTENNA ARRANGEMENT FOR WIRELESS SIGNALING OR THE LIKE.

1,314,095. Specification of Letters Patent. Patented Aug. 26, 1919.

Application filed May 25, 1918. Serial No. 30,782.

o all whom it may concern:

Be it known that I, GUSTAV REUTHE, a bject of the German Emperor, residing at yville, Long Island, New York, have inted certain new and useful Improvements Antennæ Arrangements for Wireless gnaling or the like, of which the follow- is a full and clear specification.

In antennæ for radiating electric oscillans, which are connected inductively or nductively with a primary circuit of any d, the potential node may be located at y point of the antenna between its upper d lower end, depending upon the manner which the capacity and inductance is disbuted. I have found that it is of particu- advantage to place the potential node such antenna within that portion of it ich is used for coupling. By this expet above all the advantage is obtained, t between the antenna portion used for pling and the primary circuit, or also ween the primary circuit and ground, y comparatively low potentials exist. refore all insulations which may be ssary at such portions of the oscillation uits may be made much lighter. Also tective devices which are frequently rered at such points in this kind of anas can be entirely dispensed with.

he control of the location of the potenl node may also be of great advantage in measuring instruments, signaling keys, , spark gaps, or any other apparatus used in the antenna circuit or adjacent ts for which a potential against ground ly undesirable.

he expedient of suitably placing the poial node is important not only for the operation of a radio station but also nearby atmospheric discharges set up l oscillations in the antenna which be of very great amplitude.

he artificial control of the potential node n antenna is however of particular in case so-called frequency changers used such as are, for instance, described illustrated in the patent to Arco-Meiss- Patent Number 1,151,566, patented May 15. In an apparatus of this character, portion of the antenna which is used coupling with the frequency changer is d on an iron core. Moreover in such the distance between the iron core he winding must be made as short as possible so as to avoid eddy currents in the iron core which may otherwise be produced by stray fields. Thus in such instance the danger of flash-overs from the winding to the iron core in case of unduly high potentials is particularly great. In such case also the primary winding of the apparatus and the rest of the station may easily be damaged.

The conditions which afford the placing of the potential node into a certain point A of an antenna are that for both portions into which the antenna is divided by this point A, the product of the effective capacity and the effective self-induction which controls the oscillations at the time must have the same value and must be equal to the product of the total effective capacity and self-induction of the entire radiation circuit. This condition can always be fulfilled by suitably distributing condensers and self-induction coils over the whole antenna. Generally these elements are variable in steps or continuously. In case the wave length of the antenna is changed it then becomes necessary to vary these elements simultaneously on both sides of the potential node.

In the accompanying drawings I have illustrated three modifications showing how my invention may be reduced to practice. Of course these modifications are only typical of the manner in which I propose to control the location of the potential node without limiting myself to the particular forms shown.

In these drawings Figure 1 shows the control of the potential node in an antenna connected at its lower end to the counter-poise.

Fig. 2 shows the control of the potential node in an antenna connected at its lower end to ground; and

Fig. 3 shows how two potential nodes may be produced in an antenna if desired.

Referring now to Fig. 1, 1 is an antenna, 2 a coupling coil for coupling the antenna with any suitable primary oscillation circuit 3. 4 is the counter-poise and 5 and 6 are two variable inductance coils, one on each side of the coupling coil 2. It may be desirable to have the potential node of the antenna located at the point A. The sum of the self-inductances 5 and 6 is given by the required wave length. Now by suitably varying the inductances 5 and 6 relatively

to each other, it is always possible to locate the potential node of the antenna at the point A.

Referring to Fig. 2, 1 is the antenna, 2 a coupling coil which in this case may be conductively coupled with a suitable primary circuit 3. In this modification the lower end of the antenna is directly connected to ground. It is again desired to place the potential node into the point A of coupling coil 2. For this purpose the inductance coils 5, 6 and 7 and the condenser 8 are provided, all of which elements are variable as shown. By suitably adjusting these elements as to relative values, the potential node can easily be placed into the point A. The most convenient way of determining whether the potential node is at the right point and for checking up the correct location, after the point has been determined, is to place a spark gap 9 of suitable size between point A and the ground as shown in Fig. 2. The elements 5, 6 and 7 are varied until the spark at gap 9 disappears. Of course any equivalent means for determining whether a potential exists between point A and the ground may be substituted for the spark gap.

Under certain circumstances it may be of advantage to have more than one potential node in the antenna. While one of these nodes may be located in the coupling coils, the other may be located in another apparatus contained in the radiation circuit. This modification is shown in Fig. 3. In this figure again 1 is the antenna, 4 the counter poise, and 10 the frequency changer of the character referred to above. 11 is an ammeter. It is now desired to have one of potential nodes located in the secondary of the changer 10 as at A and the other node located at the ammeter 11 as at A′. To accomplish this object, the inductance coils 5, 6, 7 and 12 and the condenser 8 are provided and distributed as to their location substantially as shown. Then the elements 5, 6, 7, 8 and 12 are suitably dimensioned so that the potential nodes are located at the points desired. It is of course obvious that for each given case the values of the condenser and inductances which determine the location of the node and of the wave length may be predetermined from the beginning without limiting the scope of my invention. Also it is obvious that in cases where only limited adjustments are required, only one or the other of these elements (condensers or inductances) may be made variable.

I claim:

1. The combination in a wireless signaling system of an antenna circuit, a frequency changer located therein and means for changing the natural frequency of said antenna circuit to locate the potential node of said circuit into said frequency changer comprising a plurality of inductances and a capacity distributed over said circuit and proportioned relatively to each other substantially as described.

2. The combination in a wireless signaling system of an antenna circuit, an output circuit of a frequency changer connected therein and a plurality of inductances and a capacity distributed over said circuit and adapted for adjustment to different oscillatory frequencies to locate potential nodes at predetermined points in said antenna circuit.

GUSTAV REUTHE.

[Second Edition.]

N° 14,449 A.D. 1899

Date of Application, 13th July, 1899
Complete Specification Left, 12th Apr. 1900—Accepted, 2nd June, 1900

PROVISIONAL SPECIFICATION.

Improvements in Wireless Telegraphy.

I, SIDNEY GEORGE BROWN, 22, Holland Road, Kensington, London, Electrical Engineer, do hereby declare the nature of this invention to be as follows:—

This invention relates to improvements in wireless telegraphy especially in the method of arranging the radiating and receiving wires.

The transmitter and receiver may be provided with two vertical or horresontal wires, a wire coupled to each side of the spark gap, or receiving coherer, and placed oppoximately at say half a wave length apart, with or without an earth connection.

These wires may or may not be closed at the top, or joined through a small capacity, and a rectangular or other shape may be given to the wires so as to enclose an area.

If a spark gap at the generating station is provided with vertical wires, earth connections or other equivalent devices, the wave length the whole system shall generate can be settled and fixed by placing suitably shaped insulated conductors between the two outer spark balls, or by arranging the immidiate surroundings of the spark gap, by these means a reflector preferably constructed of straight or wire gauze can be placed behind such radiating wires, and within a much shorter distance than the whole or half length of such vertical wire.

Instead of an earth connection, the other side of the spark gap may be coupled to the reflector which may be insulated, the vertical wire being held in place by suitably shaped insulators fixed to the reflector.

I have found it convenient in many cases especially if the vertical wire was connected to one of the middle balls of the spark gap to place a small capacity across the high-pressure terminals of the spark coil, an inductive circuit being placed if necessary between such capacity and the spark balls.

It might in many cases be more convenient to multiply the number of radiating systems rather than increase the height of the wires.

In this case it would seem convenient to have separate windings on one spark coil for all the systems, while if the receiver was to be treated in a similar way I should place vertical wires one behind the other and having some relation to the wave length, and coupled in series.

Dated this 13th day of July 1899.

SIDNEY GEORGE BROWN.

COMPLETE SPECIFICATION.

Improvements in Wireless Telegraphy.

I, Sidney George Brown, 9, Putney Hill, Putney, "late of" 22, Holland Road, Kensington, London, Electrical Engineer, do hereby declare the nature of this invention and in what manner the same is to be performed, to be particularly described and ascertained in and by the following statement:

According to this invention the transmitting apparatus is provided with two radiating wires coupled one to each terminal of the sparking device and the receiving apparatus is provided with two receiving wires coupled one to each terminal of the coherer.

These radiating and receiving wires are respectively placed at a distance apart which has a definite relation to the length of the signalling waves, that of half a wave length being a convenient distance.

The said wires may be closed at the top or not and they may or may not be provided with an earth connection.

This placing the wires half a wave length apart causes the system to send its waves or receive them from mainly one direction, which direction would seem to be that of the plane of the wires.

If the vertical wires were not so carefully adjusted to the wave length they would transmit or receive the Hertzian waves from any direction.

The vertical wires may or may not be closed at the top or joined through a small capacity and a rectangular or other shape may be given to the wires, and the rectangle may consist of more than one turn of wire, so as to enclose an area.

By arranging a condenser across the high potential terminals of the spark coil and joining the terminals of this condenser to the spark balls through highly inductive coils I can increase the persistance of the waves; the condenser acting as a storage of power, and maintaining the potential at each side of the spark gap.

The highly inductive coils prevent the charge in the condenser from itself oscillating across the spark gap.

By thus increasing the persistance of the train of Hertzian waves due to each disruptive discharge, the receiving circuit can be caused to be in tune or syntony with the transmitting circuit, thus rendering the system more sensitive and less likely to be interfered with by neighbouring systems differentially disposed.

The wave length that any system may generate is to a certain extent under command and it is necessary if parabolic reflectors are to be used to keep the waves short.

This can be done by suitably arranging the spark gap, such as by employing suitably sized intermediate balls or by placing inductive coils on the arms of the radiating wires.

By thus keeping the length of the waves short the use of parabolic mirrors behind the radiating and receiving wires and within a much shorter distance of said wires than that of their length or half their length as has heretofore been thought necessary is rendered possible.

These mirrors which should be constructed of reticulated metal such as fine wire netting or its equivalent, have the effect of reflecting the waves to, or receiving them from one definite direction and thereby restricting the wave or telegraphic effect to a given direction.

In order that my invention may be clearly understood and readily carried into effect I will proceed to describe the same more fully in connection with the accompanying drawing in which.

Figures 1 and 2 are respectively diagrams of transmitting apparatus and

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receiving apparatus in which the radiating and receiving wires project vertically into the air.

Figures 3 and 4 are respectively diagrams of transmitting apparatus and receiving apparatus in which the radiating and receiving wires are put to earth.

Figure 5 shows a parabolic mirror in position behind a radiating or a receiving wire arranged according to this invention.

Referring to Figures 1 and 2, a and a^1 are the radiating wires of the transmitting apparatus, a^2, a^3 are the receiving wires of the receiving apparatus and are preferably arranged in the same plane with the wires a a^1. b is the battery and t is the transmitting instrument, in the primary circuit of the induction coil C of the transmitting apparatus.

K is a condenser placed across the high potential terminals of the secondary winding of the induction coil C.

S S S are the spheres or balls of the sparking device.

L L^1 are inductive coils placed between the terminals of the condenser K and the terminals of the spark balls S S, the ends of the radiating wires a a^1 at one extremity being also respectively connected to the terminals of the said spark balls.

V is a rotary vibrator of well known construction placed in the primary circuit of the coil C.

R is the receiving relay or other receiving instrument b^1 is the battery in the circuit of the receiving relay d is the coherer in the receiving relay circuit, to the terminals of which coherer the wires a^2 a^3 are connected.

L^2 L^3 are inductive resistances placed respectively between the terminals of the coherer d and the receiver R and battery b^1 but in many cases L^2 L^3 are unnecessary as the relay winding R does usually, and the shunting resistance, if used, may possess sufficient induction of their own.

Upon depressing the key of the transmitter t; which for high speed working would be replaced by a Wheatstone transmitter; the circuit of the battery b is closed and the primary winding of the coil C is energised through the vibrator V in the well known manner.

For fast speed signalling this vibrator V which makes and breaks the current for the primary winding of coil C, should be kept constantly working whether the coil C is energised or not.

When the coil C is thus energised sparks pass between the balls S and the Hertzian waves thereby generated, are radiated by the wires a a^1. The condenser acts as a storage of power, maintaining the potential at each side of the spark gap and thereby increasing the persistance of the waves.

The coils L L^1 prevent the charge in the condenser from itself oscillating across the spark gap, whilst permitting the currents from the secondary winding of the coil C to pass steadily to the spark balls.

When no signals are received the coherer d is maintained in a decohered or non-conductive condition, and the circuit of the receiver R and battery b^1 is consequently open.

When the signalling Hertzian waves are received by the wires a^2 a^3 the said waves pass through the coherer d rendering it conductive and closing the circuit of the receiver R and battery b^1 the signals being recorded by the said receiver.

The radiating wires a a^1 and also the receiving wires a^2 a^3 are respectively placed at a distance apart which has a definite relation to the length of the Hertzian waves generated.

This distance may be conveniently half that of the Hertzian wave length, such an arrangement causing the positive radiating wire to supply the positive crest of the wave at the same time as the negative radiating wire supplies the negative crest of the wave and the waves to be thus transmitted or received mainly in the direction of the plane of the radiating and receiving wires.

In Figure 3 the battery b, transmitter t vibrator V, induction coil C, condenser K and sparking spheres S are arranged as in Figure 1.

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Brown's Improvements in Wireless Telegraphy.

The radiating wires a a^1 are respectively connected to earth plates E E and are preferably arranged at a distance of half, one and a half, or more wave lengths apart.

K^1 & K^2 are condensors respectively inserted between the terminals of the spark balls and the radiating wires a a^1.

In Figure 4 the recording instrument R the battery b^1 the inductive resistances L^2 L^1 and coherer d are arranged as in Figure 2.

The receiving wires a^2 a^3 are connected respectively to earth plates E E and are preferably arranged at a distance of half, one and a half, or more wave lengths apart and in the same plane with the wires a a^1.

K^3 and K^4 are condensors respectively inserted between the terminals of the coherer d and the receiving wires a^2 a^3.

The operation of the apparatus shown in Figure 3 and 4 is substantially the same as that shown in Figure 1 and 2.

The condensors K^1 K^2 prevent the radiating wires a a^1 being short circuited by earth and the condensors K^3 K^4 prevent the receiving wires a^2 a^3 being short circuited by earth.

The radiation (with the apparatus shown in Figures 3 and 4) keeps to the surface of the ground.

By arranging the inductive coils L L^1 and the condensor K as above described the Hertzian waves are kept persistant.

The persistance of the waves enable the transmitting and the receiving wires to adjusted in tune or syntony, so that they will be more sensitive to one another and will not be likely to be interfered with by differentially disposed neighbouring systems.

The shortness of the waves enable a parabolic mirror of wire gauze or its equivalent as e in Figure 5 to be placed a short distance behind the vertical wire e, or wires, for the purpose of reflecting the waves in a definite direction.

One side of the spark gap, instead of being earthed may be connected to the mirror e which latter would then be insulated; or if one side of the spark gap is earthed, the mirror may be also earthed, but not insulated.

In all the foregoing I may multiply the systems, coupling the wires in parallel or in series as the case might be.

Having now particularly described and ascertained the nature of my said invention and in what manner the same is to be performed I declare that what I claim is:—

1. In wireless telegraphy, the combination with the transmitting or receiving apparatus of two radiating or receiving wires, attached one to each side of the spark gap or coherer substantially as described.

2. In wireless telegraphy, the combination with the transmitting or receiving apparatus of two parallel vertical radiating or receiving wires attached one to each side of the spark gap or coherer and arranged at a distance apart which has a definite relation to the length of the signalling waves, substantially as described for the purpose specified.

3. In wireless telegraphy the combination with the transmitting or receiving apparatus of two wires attached one to each side of the spark gap or coherer, the ends of the wires being earthed substantially as described.

4. In wireless telegraphy the combination with the transmitting or receiving apparatus of two wires attached one to each side of the spark gap or coherer, the ends of the wires being connected to earth plates, which are placed at a distance apart which has a definite relation to the length of the signalling waves, condensors being inserted in the path of the wires substantially as described and for the purpose specified.

5. In wireless telegraphy the combination with the transmitting or receiving apparatus of two wires attached one to each side of the spark gap or coherer and bent so as to enclose an area.

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Brown's Improvements in Wireless Telegraphy.

6. In wireless telegraph apparatus the combination with the transmitter, the battery, the induction coil, the sparking spheres, and the radiating wires of a condenser placed across the high potential terminals of the induction coil, and inductive coils placed between the terminals of said condenser, and the terminals of the sparking spheres, substantially as described and for the purpose specified.

In wireless telegraphy, a reticulated metallic parabolic mirror or reflector placed behind the wave radiating or receiving wires substantially as described.

Apparatus arranged substantially as described and illustrated in the accompanying drawings.

Dated the 11th day of April 1900.

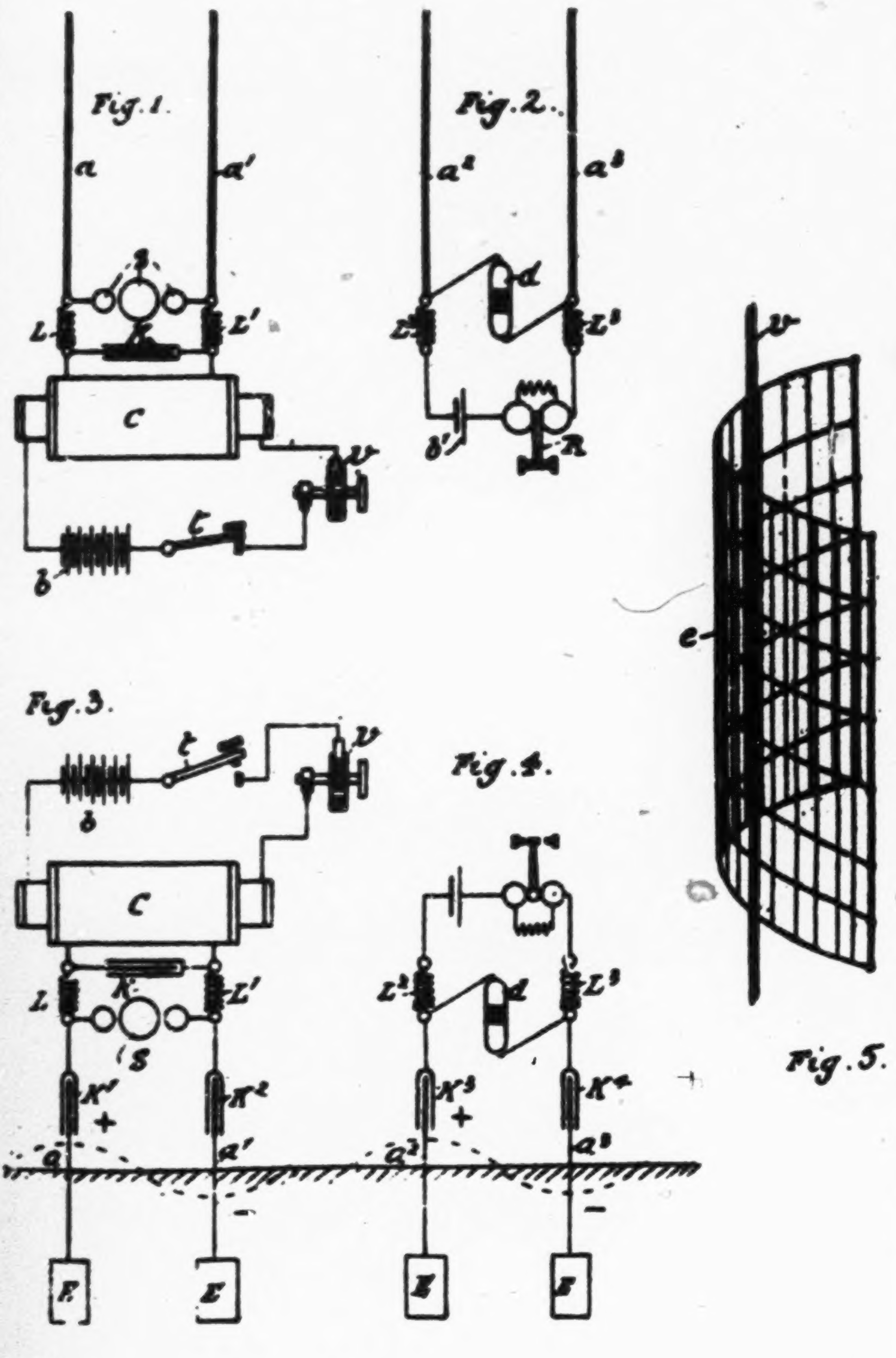
SIDNEY GEORGE BROWN.

Redhill: Printed for His Majesty's Stationery Office, by Malcomson & Co., Ltd.
[G, 361 — 125 — 6/1901.]

A.D. 1899. July 13. N° 11,449.

BROWN'S Complete Specification.

(1 SHEET)



[This Drawing is a reproduction of the Original on a reduced scale]

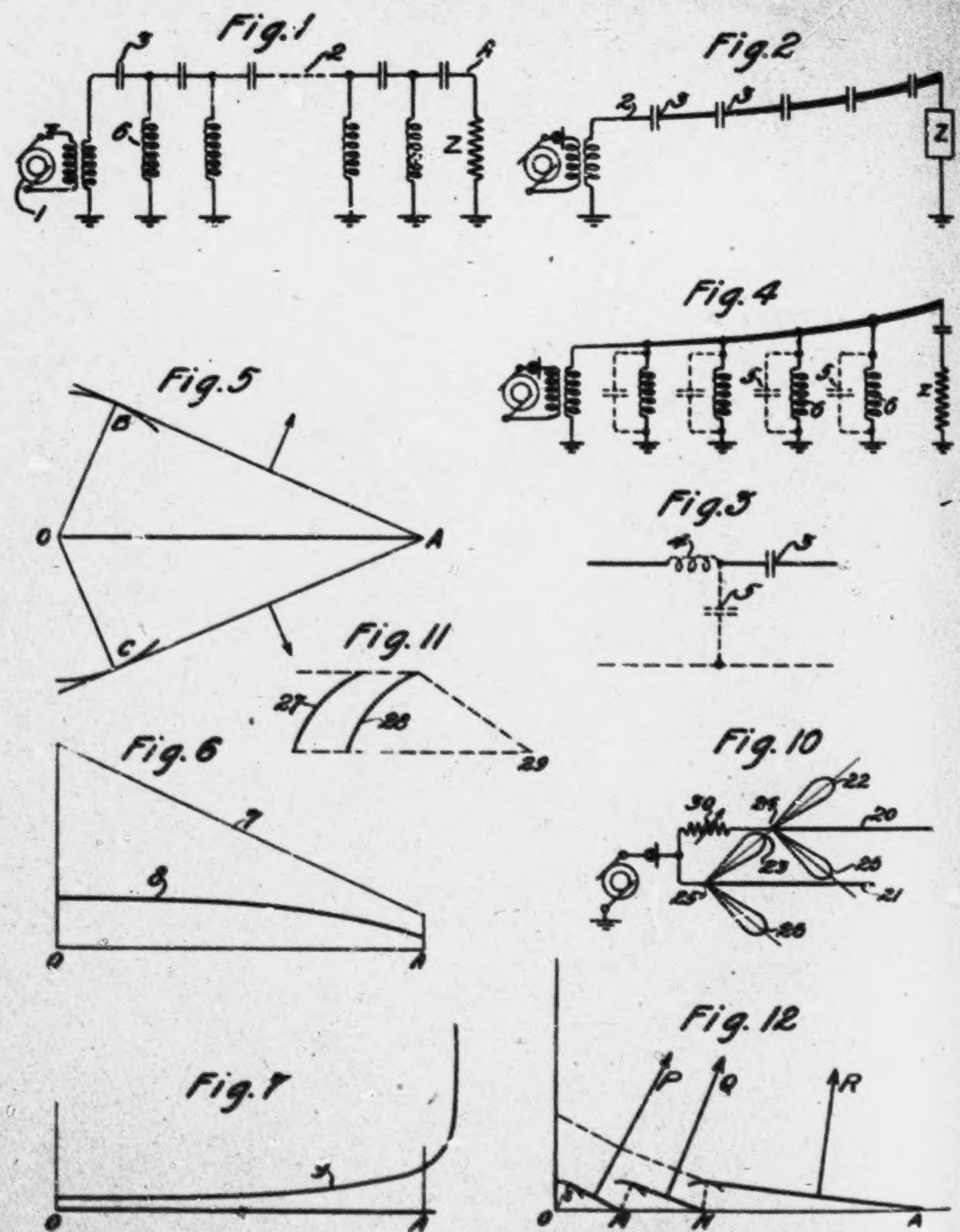
[fols. 1049-1064] DEFENDANT'S EXHIBIT AA

Nov. 24, 1925. 1,562,961

R. A. HEISING

DIRECTIVE RADIO TRANSMISSION SYSTEM

Filed May 16, 1921 4 Sheets-Sheet 1



Inventor:
Raymond A. Heising
by C. C. Sprague Att'y.

Nov. 24, 1925. 1,562,961

R. A. HEISING

DIRECTIVE RADIO TRANSMISSION SYSTEM

Filed May 16, 1921 4 Sheets-Sheet 1

Fig. 8

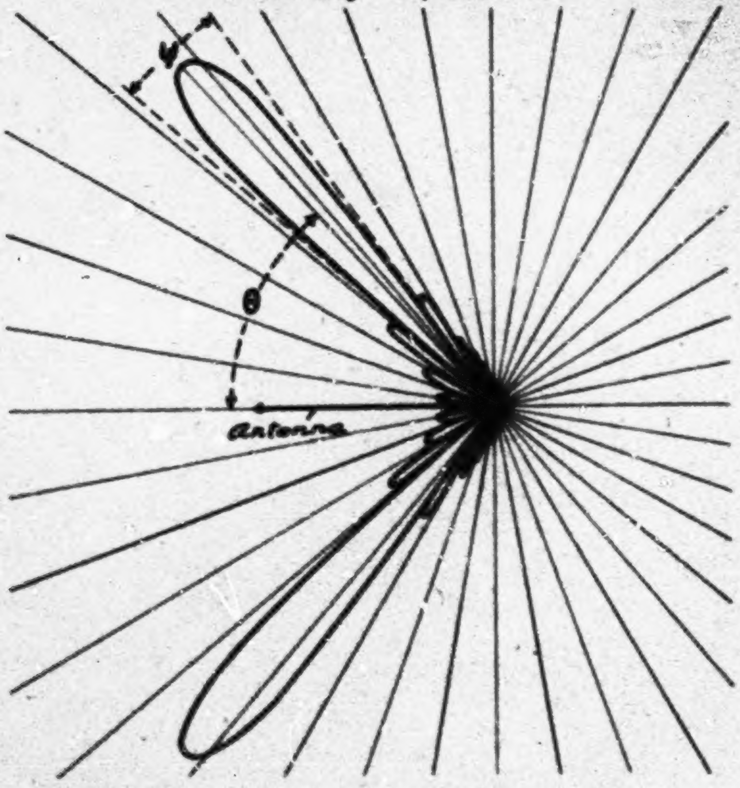
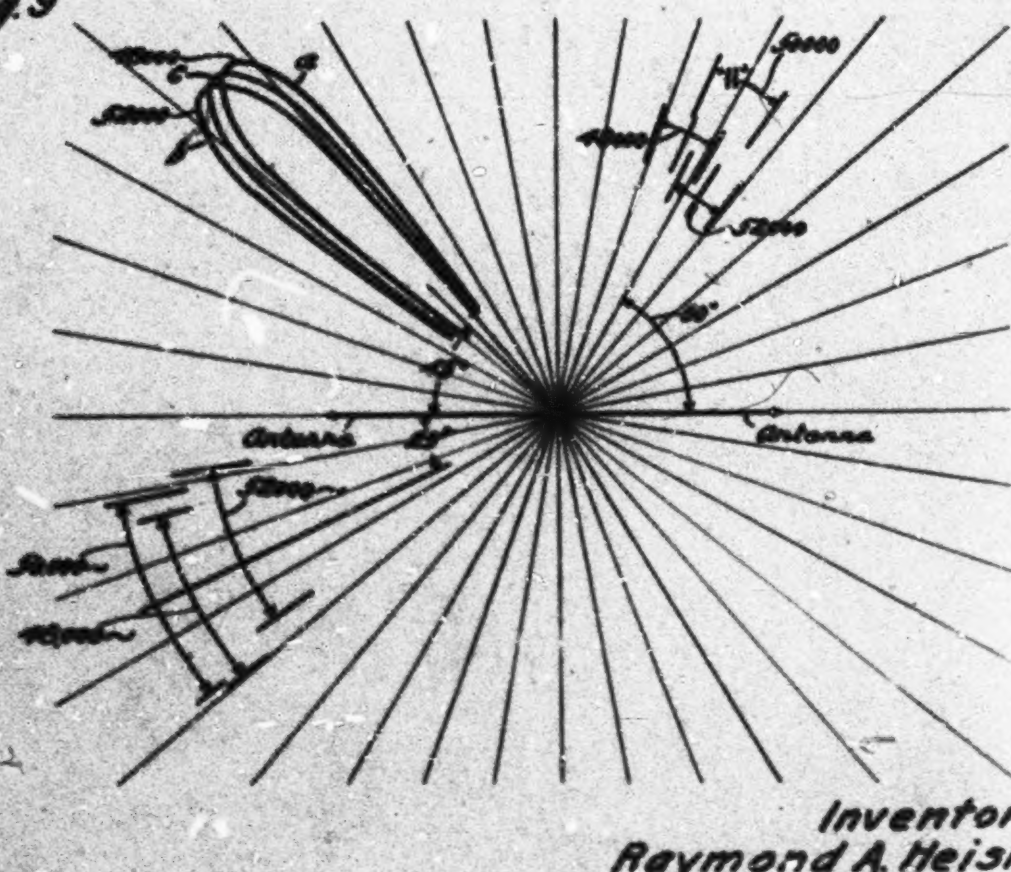


Fig. 9



Inventor:
Raymond A. Heising
by C. C. Sprague. Att'y.

Nov. 24, 1925.

1,562,961

R. A. HEISING

DIRECTIVE RADIO TRANSMISSION SYSTEM

Filed May 16, 1921

4 Sheets-Sheet 3

Fig. 13

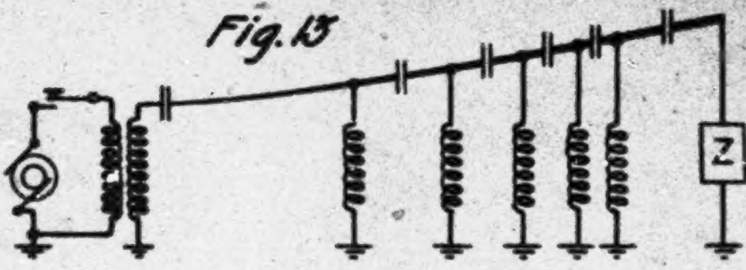


Fig. 14

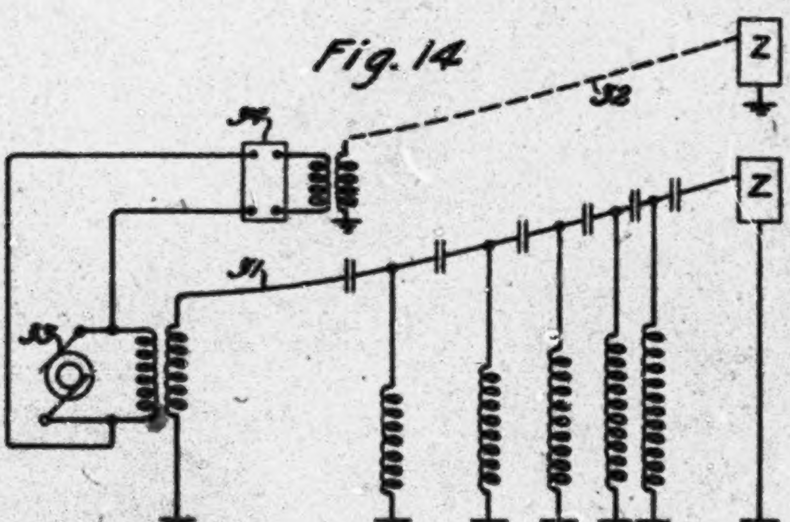


Fig. 16

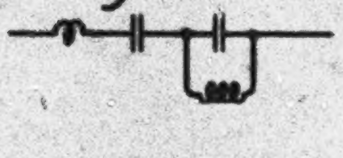


Fig. 15

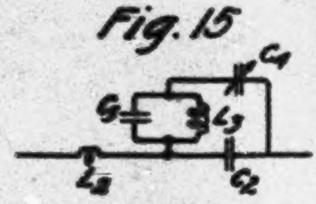
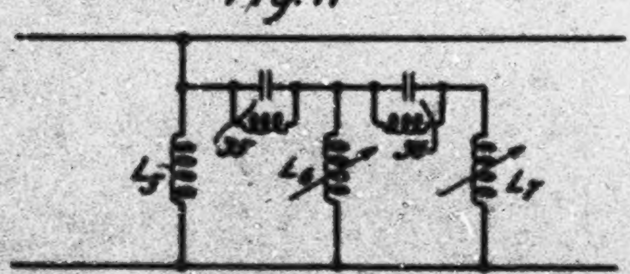


Fig. 17



Inventor:
Raymond A. Heising
by C. C. Sprague Att'y.

Nov. 24, 1925. 1,562,961
R. A. HEISING
DIRECTIVE RADIO TRANSMISSION SYSTEM
Filed May 16, 1921 4 Sheets-Sheet 4

Fig. 18

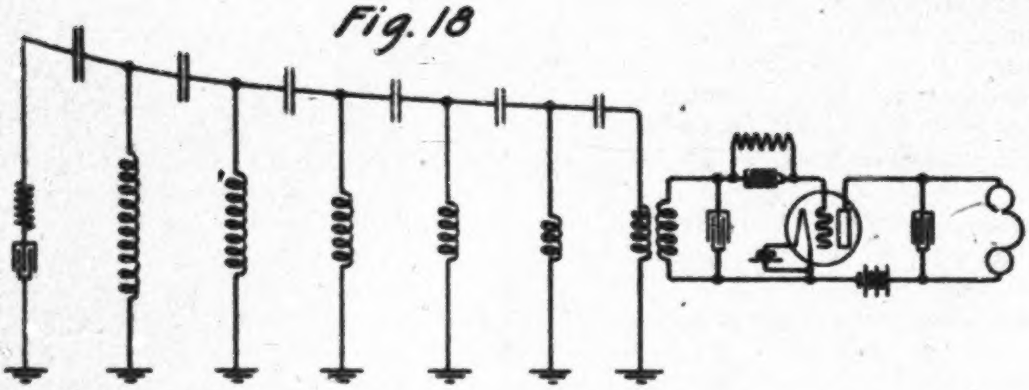
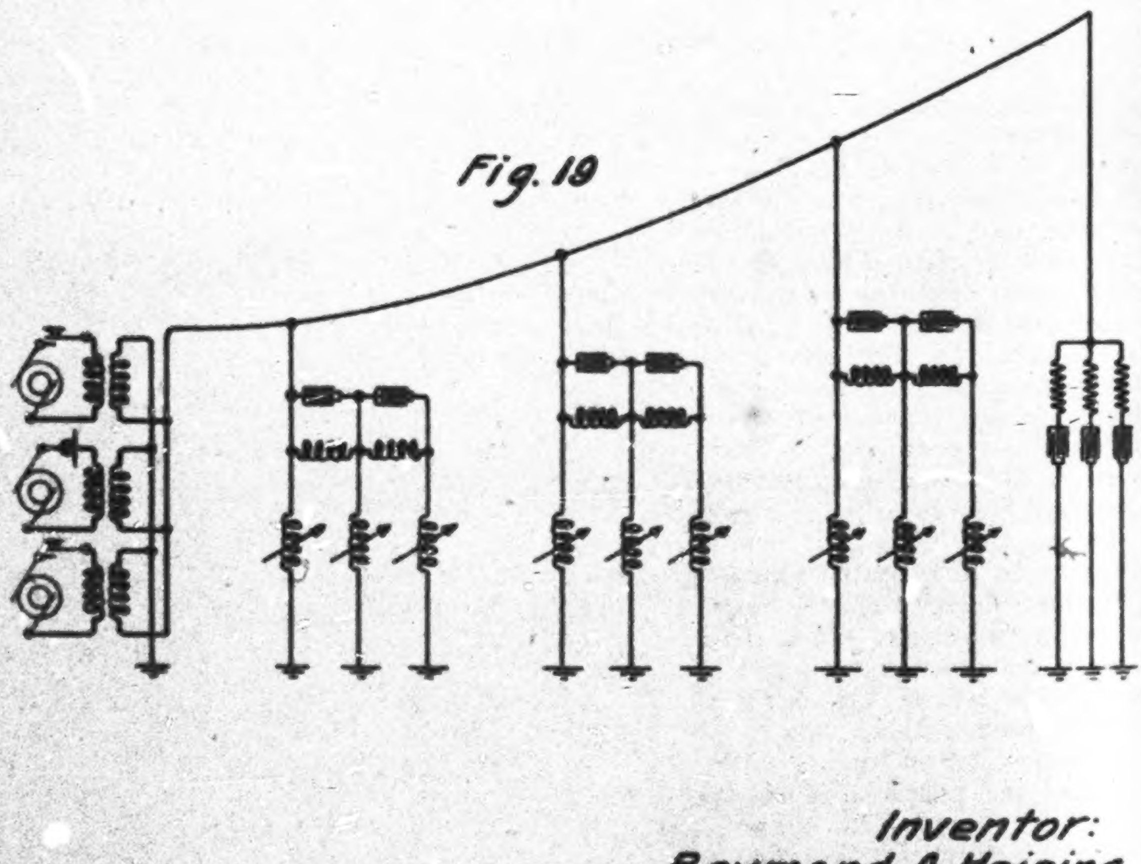


Fig. 19



Inventor:
Raymond A. Heising
by C. C. Sprague Att'y.

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1,562,961

Patented Nov. 24, 1925.

UNITED STATES PATENT OFFICE.

RAYMOND A. HEISING, OF MILBURN, NEW JERSEY, ASSIGNOR TO WESTERN ELECTRIC COMPANY, INCORPORATED, OF NEW YORK, N. Y., A CORPORATION OF NEW YORK.

DIRECTIVE RADIO TRANSMISSION SYSTEM.

Application filed May 16, 1921. Serial No. 470,042.

To all whom it may concern:

Be it known that I, RAYMOND A. HEISING, a citizen of United States of America, residing at Milburn, in the county of Essex, State of New Jersey, have invented certain new and useful Improvements in Directive Radio Transmission Systems, of which the following is a full, clear, concise, and exact description.

This invention relates to directive transmission of energy and more particularly to methods of and systems for directively radiating and absorbing electric waves.

An object of the present invention is to provide a transmission system for radiating energy directively. Another object of the invention is to provide a focussing antenna which will concentrate the radiated energy at a distant point.

The propagation velocity of wave in any medium is in general the product of its frequency and its wave length in that medium. In the case of free electric waves, the propagation velocity is approximately 300,000,000 meters per second. In the case of guided electric waves, the wave length and the wave propagation velocity are functions of the electrical constants of the guiding transmission conductors. As given by Heaviside, the wave lengths of a sustained wave over a circuit having uniformly distributed inductance and capacity is

$$(1)\quad \lambda=\frac{2\pi}{\sqrt{\frac{1}{2}\left\{\sqrt{(SR+\omega^2LC)^2+\omega^2(LS-CR)^2}-(SR-\omega^2LC)\right\}}}$$

where λ is the wave length, ω is the angular velocity or the wave frequency multiplied by 2π and S, R, L, and C are respectively the shunt conductance, series resistance, series inductance, and shunt capacity of the circuit per unit length. This wave length evidently depends upon the magnitudes of these four electrical characteristics per unit length of the circuit. By varying these it is possible to increase or decrease the wave length of the sustained wave and accordingly to vary the wave propagation velocity along the circuit. If a loaded circuit of this character is used for radiating or absorbing electric waves, the waves, if sustained sine waves, may be propagated along the circuit at a greater velocity than that at which they progress in the ether. If a definite small part of a transmitting antenna be considered, the energy of the wave proceeding from that part will be partly propagated along the circuit as a guided wave and partly radiated and propagated out through the surrounding space. The shape of the resultant wave front in the ether will be dependent upon the relative velocities of wave propagation in the two media. It is, therefore, possible to give a radiated wave variously directed fronts depending upon the loading of the antenna circuit. It is likewise possible to so absorb the directed radiant wave at a receiving antenna as to cause all of the absorbed energy to cumulatively affect the receiving device.

According to the present invention a radio transmitting or receiving antenna is made long with respect to the wave-length of the wave to be transmitted or received. In order to make this antenna behave as a conductor of infinite length and thereby avoid the production of a reflected wave, it is desirable to terminate it in an impedance element having an impedance equivalent in magnitude and character to the iterative or surge impedance of the antenna itself at the terminating point. At intervals corresponding to a fraction of a wave-length, the antenna is loaded by inserting series capacity or shunt inductance or both to make its wave propagation velocity for the waves to be transferred higher than the corresponding wave propagation velocity in ether. Since the energy in a radiating antenna decreases with increasing distance from the source, it is desirable in order to secure the best results to progressively increase the radiating factor of the antenna and this is done by increasing its height.

The invention permits radiation in one lateral direction to the substantial exclusion of radiation in any other by an arrangement of parallel antennæ. For focussing on a

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fixed receiving point the loading of the transmitting antenna may be progressively increased so as to progressively change the direction of the wave front of the emitted wave. The antenna may also be curved laterally to add to the focussing effect. For multiplex operation, waves of a plurality of different frequencies may be focussed at the same or different points by loading the antenna in different manners for waves of each of the different frequencies.

Other objects of the invention will be apparent upon consideration of the following detailed description taken in connection with the accompanying drawing in which Figure 1 illustrates diagrammatically a loaded antenna long with respect to the wave length of the emitted wave; Figure 2, a radio transmission arrangement including series capacity loading for increasing the wave propagation velocity; Figure 3, a unit section of the conductor of Figure 2; Figure 4, an antenna system provided with shunt inductance loading; Figure 5, a diagram indicating the directive operation of loaded antennae; Figure 6, a diagram of current and energy distribution in antennae of the type disclosed; Figure 7, the radiating coefficient diagram for antennae of this type; Figure 8, a polar diagram showing the distribution of the radiated wave amplitude in various angular zones; Figure 9, a polar diagram showing the distribution of energy of a modulated carrier wave; Figure 10, an antenna system for neutralizing the directed energy in one direction; Figure 11, an arrangement of laterally curved antennae for focussing energy at a distant receiving station; Figure 12, a diagram indicating the operation of a second type of focussing system depending upon progressive change in loading; Figure 13, an antenna arrangement for this second type of system; Figure 14, a directive focussing system employing both capacity and inductance loading; Figures 15 to 17 illustrate details of loading arrangements applicable to any of the foregoing systems; Figure 18, a receiving system with a loaded antenna; and Figure 19, a multiplex system for focussing a plurality of different waves.

Referring to Figure 1, a source 1 is associated with an antenna 2 to supply energy thereto for radiation. Antenna 2 is preferably of a length several times the wavelength defined in equation (2). This wavelength depends upon the inductance and capacity per unit length of the radiating circuit. In loaded telephone lines with inductance, as is the common practice, the wavelength is greatly shortened. In fact, in loaded line telephone practice, the wavelength multiplied by the frequency may give a velocity of the order [illegible]000 meters per second instead of 300,000,000 meters per second which is the velocity of light and of free electric waves. Since increasing the inductance per unit length which is done in loading telephone lines, shortens the wave length at a given frequency, it will be evident that it is possible by reducing the inductance per unit length, to increase the wave-length of a unit circuit. If the resistance and shunt conductance of the circuit are made zero, equation (1) reduces to

$$(2) \quad \lambda = \frac{2\pi}{\omega\sqrt{LC}}$$

From equation (2) it would appear that, with circuits of negligible series resistance and shunt conductance per unit length, either reducing the series inductance per unit length or the shunt capacity per unit length, should increase the wave length and, therefore, increase the velocity at which a given frequency wave is propagated along the circuit. This can actually be accomplished in several ways it being remembered that the long antenna with its capacity to ground and the return ground conducting path may, if uniform and if properly terminated, be treated as any other alternating current conducting circuit. One simple way to increase the velocity of the wave propagation is illustrated in Fig. 1 in which series loading capacities 3 and shunt inductances 6 are inserted in the conducting line and are spaced much in the same manner as are the loading inductances in loaded telephone lines. These loading inductances and capacities should be separated by distances small compared to a wave length, so that the effect of uniform distribution of the capacity is approximated. Although the exact number of such elements may vary greatly, it is desirable to use eight or more per unit length. For simplicity only a few elements are shown. The action of this capacity loading is to introduce series reactance opposite in sign to that of the natural series inductance, and accordingly to produce lower effective series inductance per unit length. The action of the inductance loading is to introduce shunt reactance opposite in sign to that of the natural shunt capacity and hence to produce lower effective shunt capacity reactance per unit length. It will, of course, be understood that either series capacity loading or shunt inductance loading alone may be used.

As has been previously mentioned, a circuit of this character of finite length must be properly terminated to avoid having a wave reflected from the free terminal. A reflected wave produces nodes along the circuit and introduces complications of various sorts. If the transmitted wave gives directive radiation in the general direction of its transmission the reflected wave will give

directive radiation in the opposite direction. To eliminate the reflected wave and prevent this reverse transmission, it is only necessary to terminate the line with a proper impedance Z, the value of which may be computed from well known transmission equations.

Fig. 2 illustrates a modification of the arrangement of Fig. 1 in which series capacity loading is employed. Conductor 2 is progressively elevated to increase the radiating factor so as to maintain the energy radiation as nearly equal as possible at all points along the antenna. To maintain the unit shunt capacity constant with increasing height a conductor of increasing size is employed. An element of the recurrent network thus formed is illustrated in Figure 3, in which the natural series inductance 4 and shunt capacity 5 of the conductor, both indicated by dotted lines, constitute together with the loading capacity 3 a uniform section of the line.

Fig. 4 illustrates another method of antenna loading which consists in reducing the effective shunt capacity of the circuit. This is accomplished by connecting between the line and ground, loading inductances 6 which are preferably spaced eight or more to the wave length, although in this case as well as in the case of the series capacity loading, a considerable variations in this number may be permitted. It is a well known fact that the effective capacity of a condenser is reduced by connecting in parallel with it a large inductance. The effective reactance of the condenser is increased. At a given frequency the natural capacity 5 of a unit section of the conductor with the inductance 6 shunted around it has several times the capacitative reactance which the capacity 5 alone has. Resistance tends to shorten the wave length. It is accordingly desirable to make the resistance of the antenna conductor very low. In loading systems of the kind described, the variations in effective capacity or effective inductance will be particularly marked for a given frequency, and wave velocities for such frequencies may be attained exceeding that of light.

The fact that a wave may be made to travel over a circuit with a velocity greater than that of free electric waves or light, may be made use of in directive transmission. Referring to Figure 5 in which OA represents a plan or top view of a long loaded antenna of the type illustrated in Figures 2 and 3, suppose that the source of waves is located at terminal O. An electrical disturbance occurring as an alternation of electrical potential at this point travels along the circuit to a point A. By radiation point O becomes the center of a disturbance of like form which emanates in all directions through space. If the space velocity, i. e., the velocity of free electric waves is such that the radiated wave travels a distance OB during the time that the guided wave travels the distance OA, the wave front of the radiated wave in the space surrounding the antenna will take the directions BA and CA. The direction of propagation of the radiated wave being perpendicular to this front is indicated by the arrows. The angle between this wave front and the antenna evidently depends upon the ratio of the guided wave velocity to the free wave velocity. If right angle triangles are drawn similarly to Fig. 5 for the case where the base OA equals the radii OB and OC, the hypothenuses AB and AC will be infinitely short and at right angles to the base OA. This illustrates the critical case in which the ratio of velocities is unity. When this ratio is unity, the wave will accordingly be propagated in the direction of transmission along the circuit, i. e., OA. The physical basis for the phenomenon when the ratio is unity is made readily apparent by noting that as the wave is radiated in the direction of antenna OA, since the wave is propagated along the antenna at the same velocity, new centers of oscillation are continuously being established on the wave front which in turn gives rise to waves which travel in the direction OA coincidentally with those from the original wave source O and having the same phase. There accordingly results a reenforcing of the wave in the direction OA. The original wave and the waves radiated from these centers of oscillation in the opposite direction are opposed in phase and mutually extinguish each other. When the ratio is infinite the wave front will obviously be parallel to the conductor and the direction of propagation will be perpendicular to the antenna. When this ratio is less than unity, the antenna is not directive.

In Figure 4, the terminating element Z is shown as comprising series resistance and capacity. That the terminating impedance may be closely approximated by resistance alone will be evident from a consideration of the specification of United States patent to Heising 1,313,483, patented August 19, 1919.

In order to secure best results, the directed wave should be of uniform intensity throughout its wave front. This requires that the radiation in power should be the same for each unit length along the line. In a line having uniform resistance, inductance, and capacity, the current decreases logarithmically, and the radiation will accordingly be non-uniform. If the energy is to be uniformly radiated, the remaining energy in the guided carrier wave should decrease uniformly from the terminal O of the antenna to the terminal A, where the remainder of the energy should be absorbed by the terminating impedance Z. In order

to secure an energy distribution of this character as illustrated by line 7 of Figure 6, the current along the circuit must vary as the square root of the energy as represented by curve 8 of Figure 6. In order that the radiated power may be uniform along the line with decreasing current, it will be evident that the radiating constant of the antenna or its radiation resistance must be gradually increased along the line. It should vary according to the reciprocal of the square of the current amplitude, as indicated by curve 9 of Figure 7 which represents the radiation coefficient or radiation resistance. Since the radiation resistance varies approximately as the square of the height of the line, this variation in resistance may be secured by varying the height of the line so as to make this height approximately proportional to the square root of the required radiation resistance. This is indicated in Figures 2 and 4 in which the height of the line increases from the source to the remote terminal in accordance with the requirement just stated. The gradually increasing height with decreasing current will produce uniform radiation throughout the length of the conductor. Inasmuch as the energy remaining at A is absorbed in the terminating network Z, it is possible to terminate the line at such a point that the height of the antenna will not, because of the very small current, be required to exceed practical limits in order to maintain constant radiation.

With an antenna of varying height and a constant size conductor, the inductance and capacity per unit length will change. It is possible to progressively vary the magnitudes of the loading reactances along the line so as to maintain the wave velocity constant. As an alternative method the diameter of the conductor itself may vary progressively with the height. With this latter arrangement the loading inductances and capacities may remain the same per unit wave length if a constant wave velocity is to be maintained throughout the length of the conductor. Figures 2 and 4 indicate a variation in the diameter of the conductor to maintain the capacity per unit length substantially constant.

Figure 8 shows a complete radiation curve with the wave amplitude as a function of its angular direction from a particular loaded line antenna of twelve times the wave length. The position and direction of extension of the antenna is indicated by the arrow. The principal energy falls within a sector of a 14° angle marked ϕ. Small amounts fall in other directions due to interference. Increasing the length of the antenna to twenty-four wave lengths would cut the angular width of the transmission loop in two and would reduce the size of the small loops representing power transmitted in other directions.

In radio telephony when modulating a carrier wave in accordance with speech, a band of waves of different frequencies results. If for example, a carrier wave of 50,000 cycles frequency is used and the range of the frequency of essential speech currents is about 2,000 cycles, the modulated energy will have frequencies ranging from 48,000 to 52,000 cycles. In a system of this kind these various frequency waves will travel along the loaded antenna with different velocities due to the fact that the effective inductive reactance or effective capacitive reactance per unit length changes with frequency. If a carrier wave of 50,000 cycles frequency is radiated from an antenna twelve wave lengths long, at a 45° angle, as shown by the curve of Figure 9, the 48,000 and 52,000 cycle frequency waves will be spread out in different directions, as shown by curves *a* and *b* respectively of the same figure. In this case the dispersion is not particularly harmful as there is sufficient amplitude of both of the extreme frequency waves occurring in the 45° angle direction to give a very good signal. Similarly, if waves of this frequency are radiated in a 25° direction, as shown in the same figure, there will be a good quality of speech transmitted from the energy produced over an angle several degrees in width. If, however, the transmission angle is 60°, as shown in the same figure, the 52,000 and 48,000 cycle waves overlap very slightly and a change in quality is apt to result. In Fig. 9, the position and direction of extension of the antenna is indicated, for the respective directions of maximum directivity, in a manner similar to that of Fig. 8.

The transmission angle depends upon the propagation velocity. A larger transmission angle accordingly requires a larger propagation velocity which in turn causes a larger difference between the propagation velocities along the line, of the different frequency components. Accordingly the differences in direction of the various frequency components, are accentuated as the transmission angle of the band as a whole is increased. If waves of frequencies lower than 50,000 cycles are used as a carrier, these variations will become still larger and it is, therefore, of advantage to use high carrier frequencies.

As is diagrammatically indicated in Fig. 5, there is directive radiation in two lateral directions. An arrangement of multiple antennae for suppressing radiation in one of these directions is illustrated in Figure 10 in which parallel directive antennæ 20 and 21 are so spaced that their respective energy transmission loops 22 and 23 from the terminals 24 and 25 connected with the

source extend in the same direction, and neutralize in space. If energy of the same phase is simultaneously supplied at points 24 and 25, and if these points are a half wave length apart in one direction in which their respective antennæ radiate most powerfully, the effect of the energy radiated from point 25 will be to oppose and neutralize that radiated from point 24 in this direction. This is for the reason that for all points in space in this direction these radiated energies will be opposite in phase. In other words loop 22 will neutralize loop 23. If the distance between the points 24 and 25 does not correspond to a half wave length, the phase of the energy supplied to one of the antennæ may be so shifted by a variable impedance device 30 that the points 24 and 25 will tend to radiate energies which will neutralize in space in the direction of the loops 22 and 23. This will leave only the loops 26 which are similarly directed and which are additive.

If it is desired to focus on a distant station, the directive antenna may be curved in direction as indicated in Figure 11 in which the two curved antennæ 27 and 28 are each given such curvature as to focus the radiated energy on a receiving station at 29. In general, in the case of curved antennæ it will be possible to obtain only roughly approximate neutralization by the use of two antennæ. Certain special cases, as for example, that where the antennæ extend along arcs of concentric circles and are arranged to focus their radiated energy at the center may give fairly exact neutralization.

A focussing effect could also be obtained by increasing the wave propagation velocity along the line so that in the region of one terminal of the line, the wave will be propagated at a greater rate than in the region of the other terminal. The operation of this will be clear from an inspection of Figure 12, in which an antenna OA is so loaded that a wave of given frequency applied at O will be propagated, in the first unit of time from O to M, in the second unit from M to N, in the third unit from N to A. Suppose that each portion OM, MN, and NA is, throughout its length, composed of like recurring sections. If the propagation velocity of the unguided waves when radiated be OS per unit of time, the radiated wave from portion OM will have a front, the direction of propagation of which is indicated by arrow P. The direction of the radiated wave of portion MN will be as indicated by Q, and that from portion NA as indicated by R. If the loading is made to progressively vary so that the wave length progressively varies, a smoothly curved wave front will obviously result. Figure 13 indicates diagrammatically an antenna loaded in this manner by a progressively closer spacing of the loading capacity or shunt inductance elements, or both. Instead of closer spacing of capacity elements of the same size the capacitances of the successively capacity elements may be progressively smaller, thus giving the same series capacity effect. In a similar manner instead of closer spacing of the shunt inductance elements, the shunt inductance elements may be uniformly spaced and their reactances may be progressively dimished in magnitude.

A desirable form of loaded antennæ is shown in Figure 14 in which the two antennæ 31 and 32, which may be either straight or laterally curved according to the arrangement of Figures 10 or 11, are arranged with corresponding points equidistantly spaced. A source 33 supplies energy to both these antennæ over parallel circuits one of which includes a phase changing device 34. This serves, as in the arrangement of Figure 10, to maintain the energies emitted from corresponding points of the two antennæ at the proper relative phases such that the energy radiated from one antenna will neutralize that radiated from the other in one direction. Each antenna comprises both series capacity and shunt inductance loading, thus combining the arrangement of Figures 2 and 4. The antennæ are progressively varied in height from the source to their remote terminals in order to maintain constant the energy radiated per unit length. Each antenna terminates in an impedance element Z which is designed to absorb the residual unradiated energy reaching the remote terminal.

Figure 15 illustrates a section of an antenna circuit loaded for waves of two different frequencies. L_1 and C_1 indicate respective series inductance including the natural inductance of the circuit and series capacity which together give a capacity reactance at one of the desired frequencies. The shunt path L_3 C_3 C_4 does not affect current of this desired frequency, since L_3 and C_3 constitute an antiresonant loop having substantially infinite impedance at that one frequency. The shunt path may, therefore, be regarded as open for the frequency considered. For current of a second frequency, the path L_3 C_3 is conductive and the net reactance of the whole unit at this frequency may be varied by varying C_4 so as to give any reactance desired for the second frequency current. Of course, an additional shunt path such as L_3 C_3 C_4 could be used for another frequency by shunting such a path about condenser C_4 and including in it a tuned loop or antiresonant circuit to exclude current of the second frequency. In this manner, the number of different frequency currents may be increased as much as desired.

Figure 16 represents a circuit having two

degrees of freedom and which can be adjusted to give the same desired reactances as are given by the arrangement of Fig. 15. This circuit may accordingly replace that of Fig. 15. Its exact adjustment is, however, considerably more difficult.

Figure 17 illustrates an adaptation of the principle of Figure 15 applied to shunt inductance loading. L_1 represents a unit shunt loading inductance designed in accordance with the principles previously laid down for currents of one given frequency. The antiresonant loop 35 tuned to this one frequency effectively cuts off the other shunt paths for such currents. The loop 35 admits currents of the second frequency and a variable inductance L_4 permits the network L_1, 35, L_4 to give the proper inductive reactance for the second frequency current. Loop 36 in the third path is antiresonant to and effectively excludes currents of the second given frequency for which variable inductance L_4 provides the desired reactance. It conducts a third frequency for which L_7 together with the rest of the network may determine the desired reactance.

Figure 18 illustrates a receiving system with progressively changing loading elements. The conventional receiving element is coupled to the antenna in the ordinary manner and is preferably designed to introduce therein the proper terminating resistance to avoid reflection loss in accordance with the principle previously stated.

Figure 19 shows a multiplex transmitting system equipped with three carrier wave sources and an antenna loaded in the manner of Figure 17. Transmitting keys are associated with two of the sources and a microphone with the third, but it is to be understood that these are merely representative of any desired arrangements for modification of the carrier waves.

Throughout the specification the various features of the invention have been explained from the standpoint of radiation at a transmission station. The principles of wave absorption are in general the same as those of wave radiation. It is, therefore, to be understood that the various features of the invention are equally applicable to receiving systems and the various circuit diagrams may each be considered as representations of a receiving system with the simple substitution of receiving apparatus for the carrier wave source.

In the appended claims the transfer of energy either by radiation from an antenna to the ether or by absorption from the ether to the antenna is analogous to the transfer of energy between media of different characteristics. In telephone parlance the term "transducing" is commonly used to describe generally a transfer of energy without limitation as to the nature of the transfer. Wherever this term occurs in the appended claims, it will be understood that it is intended to be generic both to radiation and absorption of wave energy as well as to the transfer generally of energy from a medium of certain characteristics to media of different characteristics.

What is claimed is:

1. A method of directive radio transmission, utilizing a source of carrier waves and a linear radiating conductor connected therewith, which comprises the steps of radiating a portion of the waves from said source into space, transmitting another portion of said waves along the conductor, absorbing a portion of the energy thus transmitted at points in the conductor, radiating the absorbed energy from said points and preventing reflection of the unabsorbed transmitted waves at the remote terminal.

2. The method of wave transmission which comprises radiating from a conductor very long with respect to the wave length of the radiating energy an amount of energy per unit length of said conductor substantially uniform throughout the entire length of said conductor.

3. The method which comprises propagating an electric wave along a linear conductor at a wave propagation velocity exceeding that of light and radiating a substantially uniform amount of wave energy from each unit length of said conductor.

4. The method of directive radio transmission, utilizing a conducting element, which comprises propagating said waves along the conductor, causing the propagated velocity to differ in a systematic manner at different points in said conducting element, absorbing a portion of the energy from the wave propagated thereacross at each element of the conductor, and radiating said absorbed energy.

5. The method of directive transmission comprising propagating waves along a conductor at a velocity exceeding that of light and progressively varying the velocity of propagation throughout the length of the conductor.

6. The method of electric wave transmission, using a long conductor, which comprises supplying periodic energy to said conductor and propagating it at progressively increasing velocities throughout the length of the conductor.

7. A loaded circuit having loading reactances progressively varying in magnitude throughout its length so as to vary the wave propagation velocity for waves of a given frequency.

8. A directive transmitting antenna comprising a loaded circuit having its loading constants so adjusted that waves of a given frequency are propagated thereover at a velocity exceeding that of light and a termi-

nating impedance connected thereto for absorbing, without reflection, energy transmitted to said impedance.

9. In a directive radio transmitting system in combination, a transmitting antenna, a source associated therewith for supplying continuous waves to said antenna and a terminating element connected to said antenna for preventing reflection of said waves back toward said source.

10. In a directive radio transmitting system in combination, a transmitting antenna, means for supplying periodic energy thereto, said antenna being so loaded as to transmit the wave form of said energy at a velocity exceeding that of light and a terminating impedance connected to said antenna to prevent retransmission of energy back to said means.

11. In combination, a long horizontal antenna, a source of periodic energy associated therewith for supplying energy thereto, and means for causing said antenna to radiate a uniform quantity of the supplied energy per unit length of the antenna.

12. In combination, a long antenna, means connected to one terminal thereof for supplying periodic energy thereto, and means for changing the radiation resistance of said antenna progressively throughout its length so as to keep the quantity of radiated energy constant per unit length.

13. An antenna, means for supplying a periodic wave of a given frequency thereto and means for progressively varying the wave propagation velocity of said antenna whereby the radiated energy of said wave may be directively focussed upon a distant point.

14. A conductor curved upwardly throughout its length, and means for so loading said conductor as to cause it to radiate energy directively throughout its length.

15. A method of directive radio transmission, utilizing a source of carrier waves and a linear radiating conductor connected therewith, which comprises the steps of radiating a portion of the waves of said source into space, transmitting another portion of said waves along the conductor, absorbing a portion of the energy thus transmitted at points in the conductor, radiating the absorbed energy from said points, neutralizing the radiation from said conductor in one direction, and preventing deflection of the unabsorbed transmitted waves at the remote terminal.

16. The method which comprises propagating an electric wave along a linear conductor at a wave propagation velocity exceeding that of light, radiating a substantially uniform amount of wave energy from each unit length of said conductor, and neutralizing the radiation from said conductor in one direction.

17. The method of directive radio transmission, utilizing a conducting element, which comprises propagating said waves along the conducting element, causing the propagated velocity to differ in a systematic manner at different points in said conducting element, absorbing a portion of the energy from the wave propagated thereacross at each element of the conducting element, radiating said absorbed energy, and neutralizing the radiation from said conducting element in one direction.

18. The method of directive transmission comprising propagating waves along a conductor at a velocity exceeding that of light, progressively varying the velocity of propagation throughout the length of the conductor, and neutralizing the radiation from the conductor in one direction.

19. A loaded circuit having loading reactances progressively varying in magnitude throughout its length so as to vary the wave propagation velocity for waves of a given frequency, whereby said circuit tends to radiate directively in lateral directions, and means for neutralizing the radiation in one of said directions.

20. A directive transmitting antenna comprising a loaded circuit having its loading constants so adjusted that waves of a given frequency are propagated thereover at a velocity exceeding that of light, whereby said circuit tends to radiate directively in lateral directions, a terminating impedance connected to said circuit for absorbing, without reflection, energy transmitted to said impedance, and means for neutralizing the radiation in one of said directions.

21. A loaded circuit having loading reactances progressively varying in magnitude through its length so as to vary the wave propagation velocity for waves of a given frequency, whereby said circuit tends to radiate directively in lateral directions, and means for neutralizing the radiation in one of said directions, said means comprising a second loaded circuit arranged in parallel with the first loaded circuit.

22. In combination, a source of energy and connected thereto a loaded circuit having loading reactances progressively varying in magnitude throughout its length so as to vary the wave propagation velocity for waves of a given frequency, whereby said loaded circuit tends to radiate directively in lateral directions, and means for neutralizing the radiation in one of said directions, said means comprising a second loaded circuit arranged in parallel with the first loaded circuit with respect to said source and including a phase shifting means, whereby the energies supplied to said loaded circuits have a desired phase difference.

In witness whereof, I hereunto subscribe my name this 13th day of May A. D., 1921.

RAYMOND A. HEISING.

TRANSLATION DIVISION NO. BY RS WORDS FOR ITT Pat. Dept.

French Patent No. 593,570.

IMPROVEMENTS IN DIRECTIONAL ANTENNAE

Lucien Levy, a resident of France (Seine).

Applied for April 29, 1924, at 4:30 P.M., in Paris.

Granted May 30, 1925. -- Published August 26, 1925.

(Patent the granting of which has been held up in compliance with article 11, # 7, of the law of July 5, 1844, revised by the law of April 7, 1902.)

The general type of antenna used heretofore consists of one or a plurality of wires arranged in space and connected to one pole and one or a plurality of high frequency generators whose other pole is connected to the ground or to one or a plurality of wires constituting a counterpoise. In certain cases, the wires of the antenna or those of the counterpoise are connected together by cross wires which connect ~~providing~~ equipotential points.

Under these conditions, the antenna radiates a vertical electric field which is accompanied in its propagation by currents on the ground, which cause power losses.

It has been suggested, in order to prevent such losses, that the power be radiated by means of vertical antennae of several wave lengths; under these conditions, the antenna does not radiate power on the ground surface but radiates in the space comprised between two conical surfaces whose angle at the top is less than 90 degrees and whose axis is the antenna.

In the case of ordinary antennae, if diagrams are drawn with the current in the antenna as the ordinate and the wires as the abscissa, one will obtain either a curve or a surface with a single curvature.

The present application refers to improvements in antennae intended to obtain a more intense radiation of radiant energy towards the receiving pole and to favor the propagation of this energy with a minimum of loss.

With this object in mind, the present invention contemplates the use of radiating surfaces (planes for example) in which the distribution of the current is such that, if we take the current at each point as the ordinate, double curvature surfaces will be obtained. In other words, the surface being fed at high frequency at two points, the current is subject to a double propagation along ~~according~~ to two perpendicular axes.

Thanks to this double propagation, the directional effect of the antenna is much greater and, instead of obtaining a toroidal radiating surface as with ordinary antennae, one obtains only a pencil form radiation.

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Further, the invention also contemplates the use of sending antennae radiating a horizontal electric field instead of a vertical electric field, with the purpose of obtaining a greater directional effect and smaller losses during propagation.

An extremely important point, necessitating the use of a horizontal electric field, is that long distance transmission of short waves seems to be effected by reflection on the Heaviside layer. Now, it is easy to see that a horizontal electric field polarised wave will be reflected without loss of energy on a horizontal conductor plane, while on the contrary a vertical electric field wave is liable to fall under the Brewster incidence and, in that case, there will be no reflected energy. It is therefore logical to think that fading phenomena will be non-existent for horizontal electric field waves. Finally, it is desirable to point out that the parasites are very weak in a horizontal framework, for which reason horizontal electric field waves should be particularly suitable for antiparasite reception.

Horizontal antennae have already been used, but these antennae have been employed for long wave lengths and relatively very close to the ground. The invention envisages, on the contrary, horizontal antennae for the transmission of short waves and placed at a height representing an important fraction of the wave length transmitted (one quarter wave length for example). Thanks to this height and to the horizontal character of the electric field, the losses in the neighborhood of the electric antenna are greatly reduced.

It is extremely important to raise the horizontal antenna to a suitable height, greater than 1/8 of the wave length transmitted. In effect, the conductive ground effect is to give an image of the antenna. If the antenna is close to the ground this image, which radiates an inverse field to the one radiated by the antenna, partially neutralizes the effect at a distance from the antenna. This objectionable feature is avoided when the height of the horizontal antenna is comprised between $\frac{\lambda}{8}$ of the wave length $\frac{\lambda}{4}$ and $\frac{5\lambda}{8}$. In this case, in effect, the radiations of the image and of the antenna combine. It is easy to figure also the effects of inclination on the horizontal plane of the maximum energy in the vertical plane of maximum radiation, effects which are produced owing to the combination at a distance of the radiation of the antenna and of its image whose currents are out of phase by a quantity which depends upon the height at which the horizontal antenna is arranged. It will be noted that a counterpoise, consisting of a wire arranged on the surface and in or out of harmony, will permit of changing at will the phase of the currents radiated by the image and the inclination of the pencil of maximum energy.

The radiation is effected in these horizontal antennae laterally and perpendicularly to the direction of the antenna when the latter is a single-propagation antenna and according to one of the two axes of propagation of the currents on the surface of radiation when a double-propagation radiating surface is used.

Fig. 1 represents an incorporation of a shortwave horizontal antenna built according to the invention.

This antenna consists of a network of horizontal wires 1 and 2 supported between the towers 3 and 4 by swingle-trees 6 and 8 insulated from the live wires by insulators 5 and 7. Wires 1 and 2 are connected together by insulator chains 14. A high frequency generator 11 is connected, by two-wire line 9, 10, to the

antenna at 12 and 13.

Operation. While at first sight this antenna recalls the T vertical antenna, it is totally different.

Wires 9 and 10 of the supply line are traversed in opposite direction by the high frequency currents according to the arrows 16 and 17 and, consequently, the vertical radiation of the line 9 and 10 is zero.

Only portion 16-17 radiates, laterally and according to the direction 15, a horizontal electric field h and a vertical magnetic field H.

The reception of these horizontal electric field waves may be effected by means of a horizontal antenna arranged parallel to the field h and which may be either elevated or at the ground level. Thanks to the inclination of the magnetic field in the direction of propagation, it is also possible to use vertical or horizontal antennae directed in a direction perpendicular to the preceding direction.

If a receiving loop antenna is used, it should generally be placed in a horizontal plane, but reception will also be possible with a vertical loop antenna placed perpendicular to the direction from the transmitter to the receiver.

Fig. 2 is a diagram showing the distribution of the currents in the antenna. There has been provided at each point of wires 9, 10, 1 and 2 a perpendicular proportional to the current at this point at a given moment.

It will be seen that line 9-10 is a half-wave line and that the wires 1 and 2 are quarter wave length. Other distributions might also have been chosen. Any desired distribution may be obtained by combining with the antenna elements of artificial lines as provided for in Levy patent No. 506297, of October 1, 1918.

In particular, one may avoid any distribution by forming each conductor 9 and 10 of a series of elementary wires that will successively present the distributed capacity of the one to the other.

Fig. 3 represents a horizontal radiating surface for the transmission of horizontal field waves in pencil form in a preferred direction inclined on the horizontal and Fig. 4 is a diagram showing the distribution of the currents in one of the networks of this arrangement.

This surface is presented in perspective and radiates its energy in the direction of arrow 19 with a maximum radiation in the vertical plane of symmetry 20.

The radiating surface is supported schematically by the four insulators 5, 5 and 7, 7 on the four towers 3, 3 and 4, 4. The generator 11 supplies the high frequency current at 12 and 13. The high frequency currents propagate on this surface in such a way that one may consider that the half-wave system 16, 17 propagates from the front to the back of the figure. The dimensions of the surface from front to rear are such that the propagation from front to rear comprises several quarter wave lengths. One has therefore a double stationary system, one of half a wave length parallel to arrows 16, 17, and the other parallel to arrows 21 and 22 and of several quarter wave lengths. AA/16

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Thanks to the propagation 16, 17, the radiation energy is concentrated in plane 20 and, thanks to the propagation in the perpendicular direction, it is limited to a pencil inclined on the horizontal. It is easy moreover to change the inclination of the pencil by changing the distribution parallel to plane 20, for example by inserting choke coils or capacities placed on the ground level and connected to the surface by parallel conductors at 9 and at 10.

It should be pointed out that radiating surfaces may comprise a larger number of main axes ~~according to~~ which the propagation is effected, particularly one can envisage three axes forming a trihedral, and that one may thus obtain radiating beams as loose as desired.

Likewise, these surfaces may be arranged in all directions and radiate an electric field having any inclination; they may also be used as a reflector.

The use of the devices described applies to all waves, but it should be pointed out that the results are most particularly interesting for short waves less than 1,000 meters long, particularly for waves of 100 and 200 meters.

The radiating networks could also consist of metallic tubes or any other conductor.

SUMMARY

A method for long distance transmission of Hertzian radiant energy, characterized by:

1. The transmission of horizontal electric field waves to favor the reflection without loss on the Heaviside layer and on the ground and the propagation through space.

2. The energy transmitted presents a maximum in the vertical plane perpendicular to the axis of the radiator.

3. The energy is transmitted in the form of an inclined pencil accepting as the plane of symmetry the vertical plane perpendicular to the axis of the radiator.

4. The invention also covers the incorporations of the method in which:

a) The single-propagation antenna consists of two horizontal wires (or two networks) connected respectively to the two poles of a high frequency generator.

b) The antenna is placed at a height comprised between $\frac{\lambda}{8}$ and $\frac{5\lambda}{8}$ (λ = wave length transmitted).

c) The two poles of the generator are connected respectively to each of the networks.

d) Each of the networks is approximately 1/4 wave length long.

e) The horizontal antenna having a single axis of propagation radiates the energy perpendicular to its axis.

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f) The antenne having two axes of propagation consists of two horizontal rectangular networks fed by the generator at two contiguous peaks of the networks.

g) The antenna having two axes of propagation has one of its propagations half wave and the other of several quarter wave lengths.

h) The antenna having two axes of propagation radiates its energy perpendicular to the axis of half-wave propagation and in the direction going from the supply point of the surface towards the end of the radiating surface.

i) The loop receiving antennae for horizontal electric field waves consist of horizontal loops or of vertical loops perpendicular to the transmitter-receiver direction.

j) The application of these devices for transmission and reception is envisaged particularly with short waves of less than 1,000 meter wave length.

k) The arrangement of a counterpoise parallel to the antenne on the ground surface is realized in or out of harmony with the counterpoise.

L. LEVY.

A. Mathieu,
Attorney. AA/18

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Fig 1

Fig 2

Fig 3

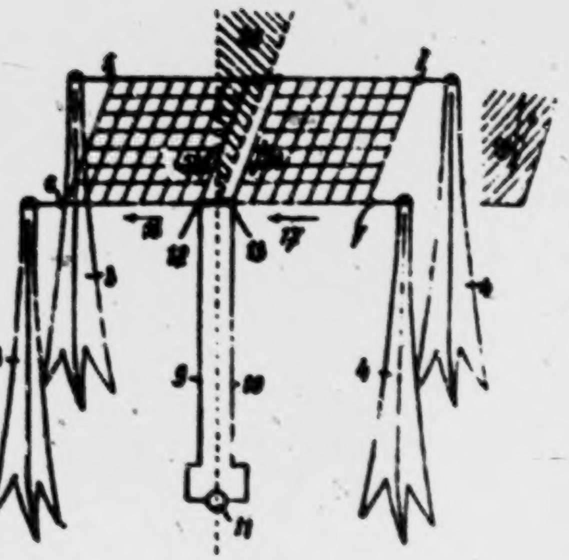

Fig 4

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First Addition to French Patent No. 593,570. No. 30,798

IMPROVEMENTS IN DIRECTIONAL ANTENNAE

Mr. Lucien Levy, a resident of France (Seine).

(Main patent taken out April 29, 1924.)

Applied for April 28, 1925, at 4:53 P.M., in Paris.

Granted June 1, 1926. -- Published August 23, 1926.

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The present addition refers to changes and improvements made in the antenna devices forming the subject of the main patent.

In the first place, it is desirable to point out that it is possible, instead of adopting the arrangements described in the main patent, to conceive of different variations which may offer advantages in certain cases, particularly where it is desired to radiate energy in a given direction.

For example, wires 1 and 2 in the arrangement shown in Fig. 1 of the main patent may, instead of being parallel to the same direction, form between themselves any angle and particularly they may be perpendicular.

Fig. 1 of the accompanying drawing shows an antenna whose radiators 1 and 2 situated on the same horizontal plane form between themselves an angle of less than 180° (the same reference numbers have been used as in the main patent to designate corresponding parts).

Likewise, the radiating surfaces of Fig. 3 in the main patent are not necessarily constituted by a lattice. Fig. 2 shows a variation of the antenna, in which the radiating networks are formed solely by the wires 27, 23, 24 and 28, 25, 26.

Finally, Fig. 3 shows an antenna device intermediate between the two types described above and consisting of two angular networks 12, 5, 5 and 13, 7, 7, themselves forming an angle and supplied at points 12, 13 by generator 11.

All these ~~devices~~ arrangements are characterized by the arrangement of radiating elements, generally horizontal, carrying high frequency currents at a sufficient height above the ground (more than a quarter wave length), the two poles of the high frequency current generator being connected respectively each to one or more radiating elements.

But it is not necessary that the divers horizontal radiating elements be fed by voltages in phase opposition, and an improvement of the invention consists in

AA/be

feeding these elements by voltages out of phase with respect to each other any quantity, constant or variable in time.

As a characteristic example of this improvement, Fig. 4 shows an antenna that permits of feeding two horizontal radiating elements by currents of any phase displacement.

In this figure, elements 29, 30, 31, 32, 33, 34, 35 correspond to elements 5, 7, 12, 13, 11. 1, 2 of the horizontal antenna 1, 2.

Generator 33 is out of phase 90° with respect to generator 11. These two generators have been shown here separately only for the simplicity of explanation, but in general they will not be different and will be replaced in an actual installation for example by two circuits of a vacuum tube installation (having one or more tubes), as described particularly in Levy patent No. 524,040.

If the two radiating elements are, for example, perpendicular and if the voltages applied to these elements are of the same frequency and out of phase 90°, an horizontal electric field will be produced, rotating at high frequency, whose radiating effects are most peculiar. This field is a circularly polarized field; its frequency of rotation is equal to the frequency F of the currents flowing over the radiators. The directional effect of the waves disappears.

However, if the radiators carry currents of the same frequency F but out of phase less than 90°, an elliptically polarized field will be obtained.

Finally, if the two radiators carry currents of equal amplitude and of frequencies F_1 and F_2—the currents of the second being out of phase 90°—, the superposition of two rotating fields will be obtained. If $\omega_1 = 2\pi F_1$ and $\omega_2 = 2\pi F_2$, the total field H is equal to $H_o \sin \omega_1 t + H_o \sin \omega_2 t$, hence

$H = 2 \sin \dfrac{\omega_1 + \omega_2}{2} t \cos \dfrac{\omega_1 - \omega_2}{2} t$; it is all as if the field of frequency $\dfrac{\omega_1 + \omega_2}{2}$ rotated at a speed of $\dfrac{\omega_1 - \omega_2}{2}$ t on an horizontal plane. The same applies to the radiated field and at any point in space a field will be obtained rotating at a speed of $\dfrac{\omega_1 - \omega_2}{2}$, which is less than the pulverization $2\pi F$ of the emission. For example, the fictitious radiating electric field and the receiving fields can be made to rotate at a speed of the order of 10,000 revolutions or even 1,000 revolutions per second.

It can also be arranged that the rotation of the fictitious radiating field be produced by the frequency modulation of one of the generators and, in this case, a new method of radio telephony can be obtained.

ANSLATION DIVISION NO. BY BS WORDS FOR ITT Pat. Dept.

By means of the new method described above, therefore, an horizontal electric eld rotating at a speed comprised between 2 F and 0 can be obtained at the ceiving station.

It is hardly necessary to emphasize the importance of this result, which permits a veritable synchronization between the sending station and the receiving station d an absolutely sure elimination of parasites which in no way present themselves the form of such rotating fields.

But the invention, as concerns the use of rotating hertzian fields, is not mited to the radiation of electric fields rotating on an horizontal plane; it mediately generalises into fields rotating in space and particularizes also into ields rotating on vertical planes and even into fixed fields in any position in pace.

For example, a vertical antenna and an horizontal antenna carrying currents out f phase 90 degrees can be combined, with the purpose of obtaining energy radiation erpendicular to the plane of the two antennae, in the form of an electric field otating on a plane parallel to the plane of the two antennae.

In the arrangement shown in Fig. 5, where the currents in the horizontal ntenna and the vertical antenna are in phase, instead of being out of phase 90°, r in the equivalent case where an antenna inclined with respect to the ground is sed for transmission, an electric field inclined with respect to the ground is ransmitted. It is to be remarked that this field enables one to tell, when in ront of a vehicle, whether such vehicle is moving towards or away from one. Let s assume that, by convention, it is agreed that, when one is in front of the front art of a vehicle, one will see the field rise from left to right. If the vehicle urns around to move away from the observer, the latter will see the field return nd consequently rise from right to left and become perpendicular to its initial osition.

A means is therefore available that may be used particularly to prevent col- lisions in the fog between vehicles or ships. In this case, in the front part of ll vehicles would be installed sets sending waves inclined 45°, equipped with eceivers of waves perpendicular to the said direction of 45°, not affected there- fore by local emissions and sensitive to emissions from dangerous vehicles.

Finally, it should be remarked that polarized light waves being in all respects dentical to hertzian waves, the invention provides a means of preventing the linding of headlight-equipped vehicles by one another. The wave sender would then onsist of a headlight (beacon) sending polarized light at 45° and the operator driver) of the vehicle whose eyes constitute the receiver would be equipped with nalyzing glasses (tourmaline or nicol), allowing the passage only of waves olarized parallel to his own emission and opposing the passage of light waves oming from the blinding headlight.

It is desirable to point out in connection with rotating fields that a new field is opened to the art and that the use of these fields should make possible a etter knowledge of the Heaviside layer and a better efficiency in radioelectric ircuits. This layer, in effect, should not act merely as a simple metallic re- flector and must present phenomena comparable to the double refraction in optics. It is possible even that phenomena may be obtained comparable to the rotation of he plane of polarization by penetration in the layer and the reflection that AA/11

should occur.

It is possible therefore that there be, after reflection on the Heaviside layer, either rotation of the plane of maximum radiation or interest in employing circularly polarized waves, either ~~dextrorsum or sinistrorsum~~. It is possible, finally, that there be produced an elliptic polarization of waves which are reflected on the said dielectric and conductive layer.

Be that as it may, horizontal electric field waves must cause phenomena much more simple and particularly permit of obtaining the means of transmitting to any distance, which is not possible with short waves polarized vertically for certain ~~medium~~ distances, the cause wherefor must certainly be the impossibility of reflecting any notable energy under the Brewster angle.

The first trials made with horizontal waves have given considerable ranges, even during the daytime and on wave lengths of the order of 80 m., with the disappearance of the fading effect. The radiation seems to take place, not only in the direction foreseen, but also in the perpendicular direction, which might be explained by the circular polarization effects mentioned above.

It should be mentioned that the generators feeding the horizontal antennae are assumed to be on the ground and connected to the radiating portion of the antenna by a two-wire line. It is evident that the latter is necessary if it is desired to keep the generator on the ground the minimum height of the antenna above the ground being fixed. But if the generator can be brought up to the height of the antenna, the supply line is eliminated. Fig. 5 shows an antenna 1[a], 2[a] of this type, installed in an airplane.

Finally, it should be noted that, by combining a vertical electric field emission with an horizontal field emission, it is possible to indicate at any moment to a vehicle its deviation with respect to the correct route. In this case, one uses an antenna of the type shown in Fig. 1 of the main patent and perpendicular to the route to be followed; the magnetic field of the vertical wave should be parallel to the electric field of the horizontal wave and reception is obtained on board the airplane with a vertical loop antenna which should give two perpendicular directions by the maximum position for the correct route. This device is used particularly to locate the entrance to a port in foggy weather.

Fig. 7 shows the arrangement ~~foreseen~~ above of a wave generating station at the height of the antenna, which ~~is directional~~ in space. Antenna 1, 2 rests on top of pylon 3, whose height is of the order of a quarter of the wave transmitted or greater than such quarter wave length. This antenna preferably consists of two rigid tubes, arranged on either side of the generator and of the length generally chosen of the order of a quarter wave or half a wave length. Joint 36 permits of directing the antenna according to all the inclinations. If the lengths exceed half (1/2) a wave length, it will suffice to turn back 180° the part of the radiator that would radiate in the direction opposite to the desired direction. Figs. 8 and 9 show radiators of this type, which could replace radiator 1, 2 of Fig. 7.

SUMMARY

The addition refers to improvements made in antennae, whereof the distinctive

features are as follows:

1. The antenna consists of two conductors situated on an horizontal plane sufficiently high above the ground and that can be connected by a two-wire line to a generator located on the ground.

2. The two conductors can be rectilinear and form an angle between themselves.

3. The radiating surfaces can consist of wire networks.

4. The radiating surfaces can be angularly arranged.

5. The radiating elements can be supplied by voltages out of phase with respect to each other, for example out of phase 90°.

6. The horizontal antenna can be combined with a vertical antenna, the two antennae carrying currents out of phase or in phase.

7. The generator, instead of being arranged on the ground, can be placed at the height of the antenna so as to eliminate the supply line.

The addition likewise covers the application of these improvements either to reveal the direction in which vehicles are moving, on land, in the air or in the water, or to show their deviation with respect to the right course, as also the application of polarized light waves to prevent blinding by headlights.

L. LEVY.

P. Degroote,
Attorney. AA/ag

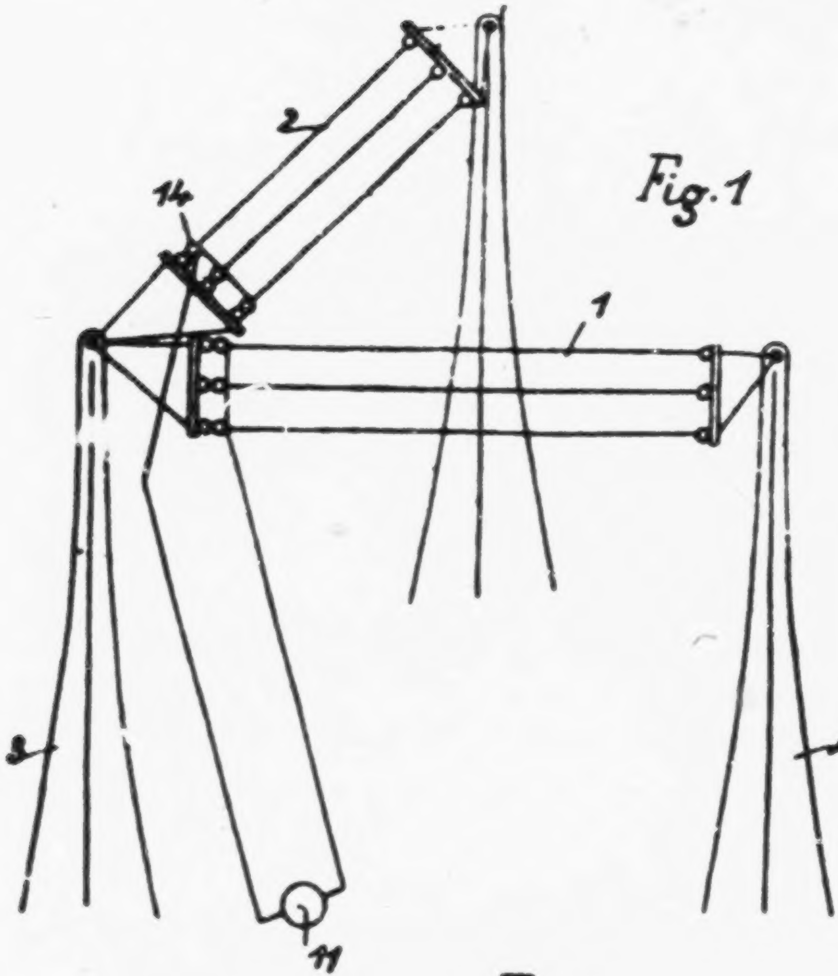
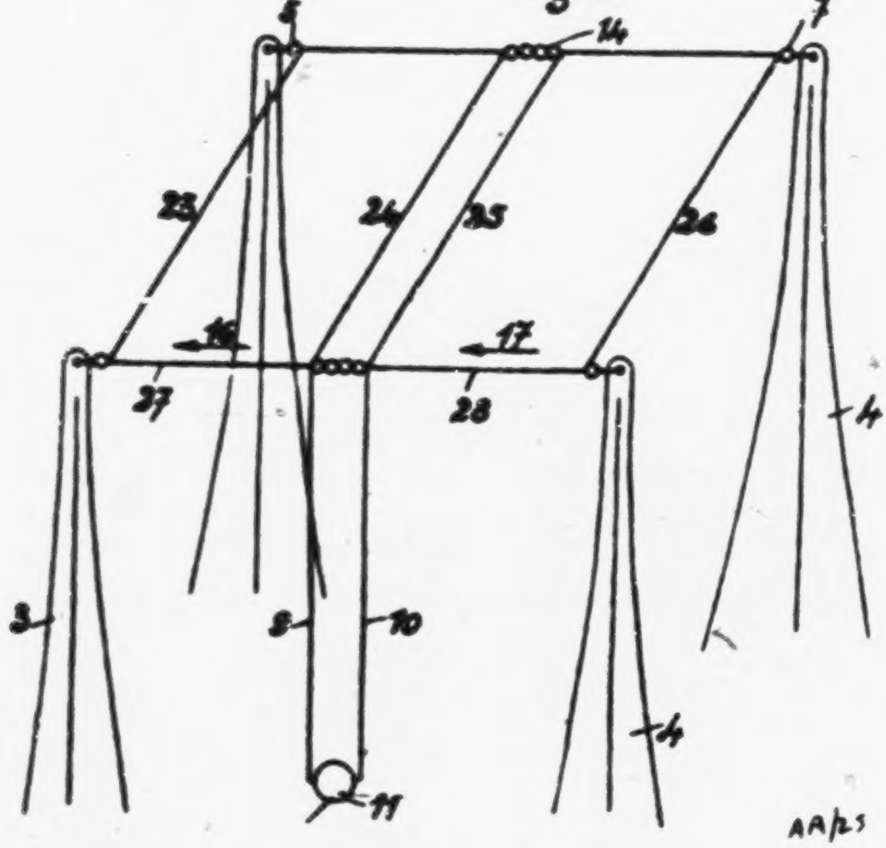


Fig. 1

Fig. 2



Fig

Fig 7

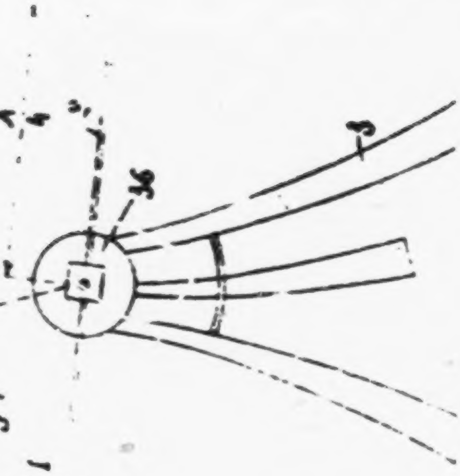


Fig 8

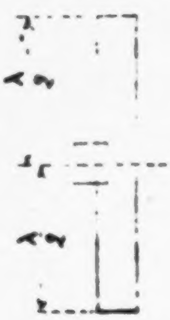


Fig 9

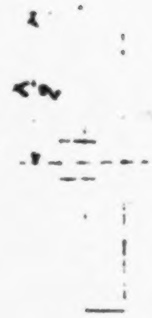


Fig 5

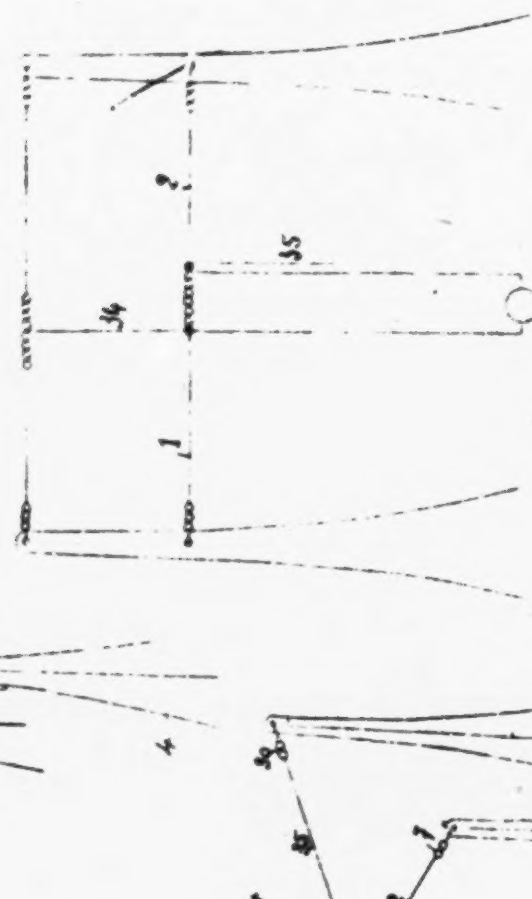


Fig.3

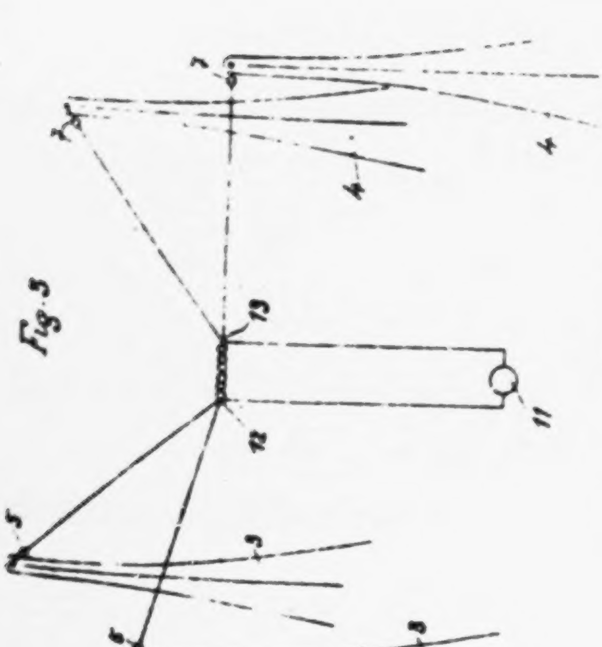
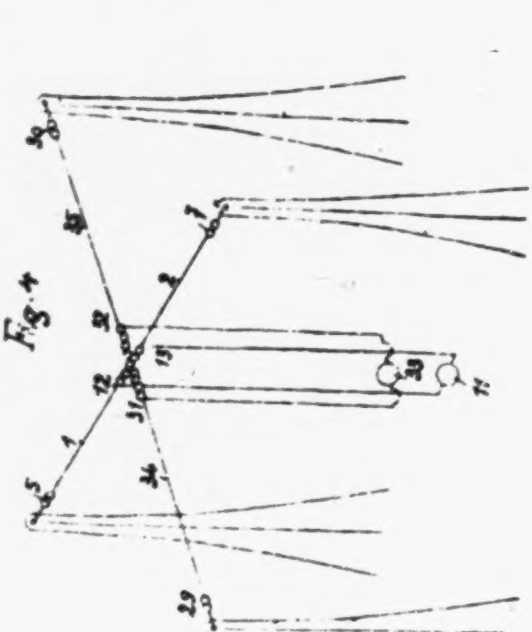


Fig.4



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QST

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Straightening Out the Antenna

By Benjamin S. Melton*

THE following article is intended to straighten out our ideas on radiating systems in general, to show why a grounded antenna can only be operated on a so-called "odd-harmonic," to suggest that a simple radiating system is probably the best and to show how to get the juice into the antenna in such a way that the antenna will be given a chance to throw it away most efficiently.

In the first place, it will simplify matters if we stop talking of antennae operating on their fundamentals, even or odd harmonics, etc. Such terms, while they may have meaning, tend to confuse our ideas, and prevent us from seeing the true conditions in a given radiating system. The terminology used in this article represents present day commercial practice. It will be seen that this terminology is logical and presents a clear mental picture of what happens in the radiating system.[1]

The Possible Antennae

Let us take a certain wave, such as 10 meters, and show some of the possible radiating systems, considering only such systems as are composed of a single conductor, either connected to earth or isolated. We shall see how this wave can be radiated from various antenna systems fulfilling certain conditions.

In the first place, (for resonance) the antenna system must have a physical length which is an integral multiple of a quater wavelength[2].

Fig. 1 illustrates the various lengths of systems, and also the names of these various lengths. The voltage distribution on these systems is shown also. It will be noticed that the "free" end of any system must have a voltage loop, or peak, as it has a current node at this point. No current can flow to or from a "free" end to ground (neglecting insulator leakage).

It may be seen from Fig. 1 that the systems which are an odd number of quarter waves in length *must be grounded at one end*, as they have current loops (corresponding to voltage nodes) at that end. A current must therefore flow to or from that end to the ground. Furthermore, it may be seen that the systems which are an even number of quarter waves in length *must not be grounded at either end*, as a high voltage

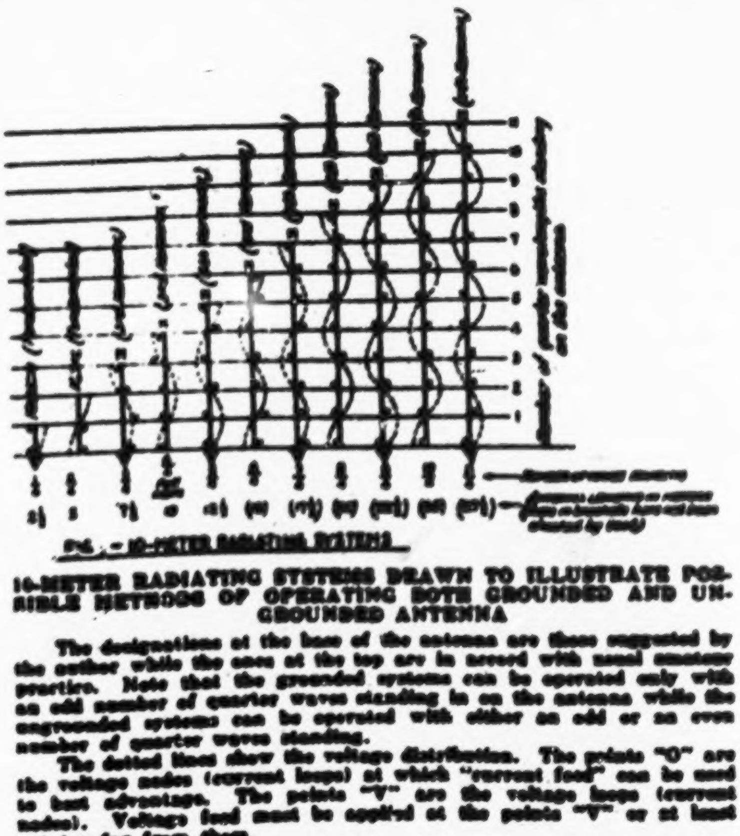

FIG. 1—10-METER RADIATING SYSTEMS

10-METER RADIATING SYSTEMS DRAWN TO ILLUSTRATE POSSIBLE METHODS OF OPERATING BOTH GROUNDED AND UNGROUNDED ANTENNA

The designations at the base of the antenna are those suggested by the author while the ones at the top are in accord with usual amateur practice. Note that the grounded systems can be operated only with an odd number of quarter waves standing in on the antenna while the ungrounded systems can be operated with either an odd or an even number of quarter waves standing.

The dotted lines show the voltage distribution. The points "O" are the voltage nodes (current loops) at which "current feed" can be used to best advantage. The points "V" are the voltage loops (current nodes). Voltage feed must be applied at the points "V" or at least not too far from them.

While the antennas shown are vertical it is possible to operate the ungrounded ones in any position. Both the grounded and the ungrounded ones may be bent instead of straight.

---

* General Electric Co., Schenectady, N. Y.

1 There is room for argument here. When we refer to closed oscillating circuits inside the station it is constantly necessary to speak of the harmonics that are present in them. It seems equally as reasonable to refer to the harmonics of the open circuit outside the station—and one set of terms answers for both purposes.—Tech. Ed.

2 Is it not surprising that this can be said without starting a violent argument. A few years ago when spark sets were universal almost all antennas were made small for the wavelength and operated with loading coils. This gave very large antenna currents and there are many old texts and governmental publications that advise operating with an antenna of the proper size to give the largest antenna current. Radiation was perhaps the most active campaigner [illegible] but this belief and gradually we have gone over to antennas large enough to be operated unloaded, or even to be operated at a harmonic—a statement [illegible] are unfortunately not able to put into the suggested terminology of the author.—Tech. Ed.

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from a point to ground cannot exist when the point is grounded.

Horizontal Antennae

Remember, also, that these systems can be made horizontally[3], except that in such a case it is not possible to ground one end *definitely*. Any wire run from one end of

FIG. 2

CURRENT-FEED SYSTEMS

A. Feed line with transformer at the antenna. See text for construction.

B. Feed line without transformer at antenna.

Both cases should have a transformer at the station end of the line.

... antenna to the ground would form part of the radiating system itself. Thus (for horizontal antennae) we are limited to systems an even number of quarter waves long.

Bent Antennae

So far we have talked about straight antennas entirely. The straight (or linear) antenna was first used by Hertz who worked entirely with vertical ungrounded systems which were put in all sorts of positions—vertical, horizontal and slantwise. Marconi probably introduced the use of the ground connection—though there is some argument about this. These are the systems marked "Hertz" and "Marconi" in Figure 1.

Now these systems become pretty large if we are to work at any but the shortest wavelengths and therefore with wavelengths above 40 meters we usually have antennas which are bent over to keep from using large and expensive towers. If such an antenna works with a ground connection it is a modification of Marconi's original scheme. It may operate with a ¼ wave standing on it or may operate in any of the ways which have an ODD number of quarter waves on the antenna—in other words it can work in any of the ways marked "M" in figure 1.

Bent Antennae with Counterpoise

If a bent antenna is worked with a counterpoise it is hard to say what type we shall classify it under. It is a double-ended affair like the Hertz antenna, yet one end is connected to the earth, (thru the counterpoise-earth capacity) which is a resemblance of the Marconi scheme. If the counterpoise is large and near the earth it is almost a a Marconi-type antenna but if the counterpoise is small and far above the ground the thing is almost a Hertz-type antenna. Some German writers get around this difficulty by referring to bent antenna-counterpoise systems as "Braun antennae" because Braun seems to have put them into commercial use first.

The name is not so important as the method of operation. Unfortunately this is not a thing about which one can make a simple statement as in the previous cases. If the counterpoise is very large it will act (as mentioned before) as a series condenser in a grounded system and the antenna will operate with an ODD number of quarter waves standing on it, just as shown for the "M" antennas in Fig. 1. Such counterpoises are unusual in amateur work although there have been some—for instance the great wheel-counterpoise at 8AQO in Cazenovia, New York. The voltage-to-ground was very small with that C. P., even when several kilowatt were being fed to the antenna. The C. P. could be touched without danger.

With the more usual amateur counterpoise the capacity to ground is very small and the system operates with an EVEN number of quarter-waves standing on it—there is voltage at both the antenna top and the C. P. ends. This means that the system works in one of the various ways labeled "H" in Figure 1.

The waves on these radiating systems are known as "standing waves." This simply means that points of zero potential (nodes) and points of maximum potential (loops) do not move along the wire in the direction of its length.

Feeding

Suppose now that we wish to excite any of these systems. There are two general methods of excitation or "feed." The first is "current feed," *usually* through electro magnetic (inductive) coupling. The second is "voltage feed," *usually* by means of electrostatic (capacity) coupling. Either of these methods may be used with any radiating system provided the current feed is not attempted at a current node, nor the voltage feed at a voltage node. See Fig. 1.

It is not necessary to use a voltage feed exactly at a voltage loop, nor a current feed at a current loop, though it is usually more convenient, and tends to give less trouble in practice, especially in the case of the current feed.

To illustrate the two types of feeding we shall consider the half-wave antenna, in a

3. For some unknown reason amateurs have begun to call the horizontal linear antenna the "Hertzian antenna". Hertz's antennae were quite as often vertical as they were horizontal. "Hertzian" had best be kept to mean a straight antenna without much (if any) loading absolutely regardless of the position the thing may have.—Tech. Ed.

AA/ot

horizontal position, and more than about one half wavelength above the ground.

Current Feed

First we shall consider current feed. There are two methods in this case, as shown in Fig. 2, though they amount to the same thing. The advantage of the second arrangement is that the antenna can be tuned somewhat from the station end of the transmission line, though such tuning shifts the voltage nodes (the single node has been split in two by the introduction of the transmission line) either out along the antenna, or down on the transmission line. It may be seen that this arrangement becomes a partial voltage feed when the voltage nodes are shifted.

Voltage Feed

We shall now consider voltage feed. One method of obtaining this is shown in Fig. 3. Though a small capacity is shown for this method, and inductance may be substituted, or the wire leading from the oscillating tuned circuit may be continuous. The requirement for correct operation is simply that there be a voltage loop or peak at the end of the feed wire. The meter in the antenna will be at a maximum when this is so. Sometimes the feed wire happens to be of the correct length to build up such a peak, sometimes an inductance or capacity is required to put the voltage loop at the correct point. It may be seen that if the feed wire itself is of the correct length for a voltage loop at its top, it will form part of the radiating system.

The single feed wire need not necessarily be connected to the end of the antenna, but instead may be connected almost anywhere between the end and the middle, although at any point between the end and the middle it forms a combination current and voltage feed.

The straight half-wave antenna is generally admitted to be the most efficient *radiator*, but this *does not* necessarily mean that it is the *best antenna* to send the energy over *long distances*, as it may not send it at the proper angle for best results. From consideration of *theoretical* angles of propagation, and from *very meager* experimental information, it is my personal *opinion* that the full-wave vertical antenna may be one of the best radiating systems for short waves.

Transmission lines used to feed antennae have many advantages, and should be used more generally than they are. Put the antenna where it will be away from other conductors, place the set where convenient, and run a transmission line of any length necessary between the two. As long as the line is well insulated and the wires not spaced too far apart (four to ten inches is O. K.), the line will not lose much energy through conductive leaks or radiation.

When coupling into an antenna by means of a transformer as shown in Fig 2A, the ratio of the primary turns to secondary turns should be the square root of the ratio of the surge impedance of the line to the resistance of the antenna, provided the primary and secondary are very closely coupled. (Unity coupling to make this statement exactly correct). The surge impedance of a no-loss line is equal to $\sqrt{\frac{L}{C}}$, and does not change much for any ordinary line, being on the order of 600 ohms. The resistance of a straight half-wave antenna unloaded is about 100 ohms, provided the antenna is some distance from the earth and other conductors, and has no large lumped inductance or capacity. Hence a good transformer turns-ratio to start with is about 2½ to 1. That is, for one turn in the antenna, use between two and two and one-half turns in the end of the transmission line, provided all turns are about the same diameter. The coupling between primary and secondary should be as close as can be obtained[4].

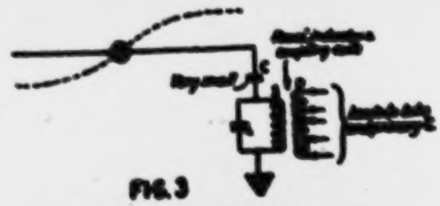

FIG. 3

A VOLTAGE-FEED SYSTEM

While the feeder is shown connected at the voltage loop (see Fig. 1) it can be connected at a point nearer the node and this is frequently done in practice. In this figure and figure 2 the antennas may be vertical, horizontal or slanting.

4. Do not confuse this with the transformer at the station end of the line. Excessively close coupling at that point will result in the usual interference difficulties.—Tech. Ed.

Strays

We desire to call to the attention of the experimentally inclined readers of *QST* a magazine which they, by all means, should be seeing, and that is *Experimental Wireless and the Wireless Engineer*, published at Dorset House, Tudor Street, London, E. C. 4. England. This magazine is always chock-full of very interesting information both of a theoretical and a practical nature. It is the official organ of the Radio Society of Great Britain and is something you really should not be missing. Incidentally it costs only 15 shillings a year and can be obtained from the above address.

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RADIO COMMUNICATION

THEORY AND METHODS

WITH AN APPENDIX
ON

TRANSMISSION OVER WIRES

BY

JOHN MILLS
RESEARCH DEPARTMENT, WESTERN ELECTRIC COMPANY, INC.
MEMBER, INSTITUTE OF RADIO ENGINEERS, AMERICAN
INSTITUTE OF ELECTRICAL ENGINEERS, AMERI-
CAN PHYSICAL SOCIETY

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station whose signals are loudest at X. If a second group of directive transmitters are at B the location of X is of course determined by simple triangulation.

Directive Transmitters.—The simplest form of directive transmitter consists of two antennæ A_1 and A_2 separated by a distance d as in Fig. 113. The currents in the two antennæ are from the same source but are out of phase. Let the current in A_1 be $Ie^{j\omega t}$ and that in A_2 be $Ie^{j(\omega t+\theta)}$. At some point p_1 distant X along the line A_1A_2 the effect[1] of antenna A_1 will be $KIe^{j\left(\omega t+\frac{2\pi X}{\lambda}\right)}$ and that of antenna A_2 will be $KIe^{j\left(\omega t+\theta+\frac{2\pi(X+d)}{\lambda}\right)}$. Let the phase θ and the distance d be so chosen that at p_1 the

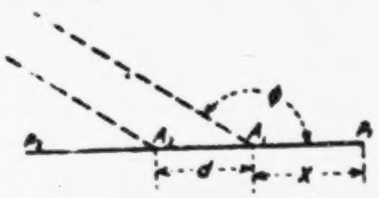


Fig. 113.—Directive transmitting with two antennæ.

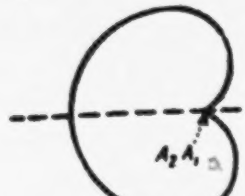


Fig. 114.—Typical direction-intensity characteristic for system of Fig. 113.

effects of the two antennæ neutralize. Then a difference in phase of π must exist between the two effects. Hence

$$\pm\pi+\left(\omega t+\frac{2\pi X}{\lambda}\right)=\left(\omega t+\theta+\frac{2\pi(X+d)}{\lambda}\right)$$

and

$$\pm\pi=\theta+\frac{2\pi d}{\lambda}\quad\text{or}\quad\theta=\pi\pm\frac{2\pi d}{\lambda}$$

Along the line A_1p_1 there will then be no transmission. Substitutions of this value of θ and of negative values of X, gives the effect in the opposite direction.

For any other direction the effect of each antenna may then be obtained in terms of the angle φ, shown in the figure, by writing $(X+d\cos\varphi)$ for $(X+d)$ in the above expressions.

[1] In this connection see the development of the wave equation of p. 112.

AA/32

If for each value of the angle φ there is plotted the resultant effect of the two antennæ a curve of the general form of Fig. 114 is obtained. The direction corresponding to the maximum is not necessarily A_1p_2 but depends upon the value of $\frac{d}{\lambda}$. This general method may be applied to determine the directive effect of any combination of antennæ

Bellini-Tosi Directive System.—In the system of Bellini and Tosi two inclined vertical antennæ A_1 and A_2 as in Fig. 115 are excited from a common tuned source S of such frequency that the currents in the two verticals are 180° out of phase. To provide for varying the direction of the maximum transmission, which is in the plane of the two antennæ, the inventors provide a second pair of antennæ the plane of which is at right angles to that of the first pair. The coupling coil M of one pair is then at right angles to that of the other pair. The coupling coil N of the source is arranged to rotate so that in one position it will have zero coupling with one pair of antennæ and a maximum with the other pair. In rotating this coil through 90° the excitation of the two directive systems is varied from a maximum for one system (through a 45° position of equal excitation) to a maximum for the other system. The direction of the electro-magnetic disturbance transmitted from the combined systems is thus variable at will.

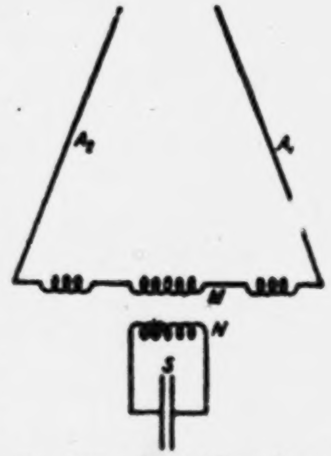


Fig. 115.—Bellini-Tosi direction system.

The apparatus is similarly applied to directive receiving in which case the rotating coil is connected to a receiving set. The position of the coil when the received signals are loudest will then indicate the line of direction of the distant source. In this form the system constitutes a "radio-goniometer."

AA/33

TRANSLATION COPY

JAPANESE PATENT NO. 70085

Classification 199
IX - High Frequency Communication - Miscellaneous

Applied for September 8, 1936
Published October 8, 1936
Patented December 27, 1936

Inventor: Eijiro Takagishi
Hiraiso Branch of Electric Experimental Station,
Hinde, Hiraiso-machi, Naka-gun, Ibaragi-ken.

DIRECTIONAL ANTENNA SYSTEM

This invention relates to a device for directional antennae and is characterized by providing for the passage of current waves from the transmitting station to the receiving station. The current waves are distributed over each conductor of the fundamental antennae. A plurality of groups of antennae are provided parallel to each other and within a plane covered by the transmitting station. Each succeeding loop of the oscillating current in a linear conductor is out of phase with respect to corresponding loops by a fraction of a whole number of 2π radians. The linear conductor is inclined at some angle other than zero degrees to the plane perpendicular to each fundamental conductor. Furthermore, the perpendicular distance between adjacent fundamental conductors is either equal to the product of the length equal to the above mentioned fraction of a whole number, the wavelength,
the cosine of a certain oblique angle, or very nearly so. — AA/34

882

1088

The purpose of the invention is to furnish a directional antenna by which a desired result can be readily obtained at will when most of the energy of the electric waves is radiated in wireless telegraphy, and wireless telephony at a given altitude, above the ground or in receiving the electric wave travelling through the air at a given angle. Furthermore, this invention makes possible efficient communication by adjusting the radiation angle depending on the distance between the transmitting and receiving stations and depending also on the seasonal and atmospheric conditions. This applies particularly to short electric waves which are noted for their properties of reflection and refraction functions.

BRIEF EXPLANATION OF THE DRAWINGS

FIG. 1 is a diagram of the antenna prepared for explaining the theory of the present invention.

Fig. 2 shows the dimensions of an antenna which was used in actual experiment and which was planned in accordance with this invention.

Figs. 3 and 4 are examples of applications of this invention.

Fig. 5-A shows another form of the arrangement of Fig. 4, while Fig. 5-B cumplifies its construction.

Figs. 6 and 7 are also examples of application

DETAILED EXPLANATION OF THE INVENTION

As a result of recent progress in studies of long distance communication by means of short waves it has been demonstrated that, if the waves are short, space waves perform a more important function than the surface waves. It has been theoretically proved that when, as has been known in the past, a vertical antenna of a comparatively short characteristic wavelength is employed for transmission, the energy of the electric waves is greatest in a horizontal direction. On the other hand, when such antenna is replaced by an antenna which has a large natural wavelength, the direction of radiation of maximum energy of the electric wave is to some extent inclined to the horizontal.

According to S. Ballantine's calculations the relation between the angle made by the direction in which maximum radiation is emitted and the horizontal plane, and the order of the harmonic in which a vertical antenna is excited is given by the following table arranged in accordance with the order of the harmonic:

No. of Harmonic	Angle against Horizontal Plane	Comparative values of Electrical Energy
3	47°	1.43
4	57°	1.65
12	77°	4.85

Therefore, in order to handle long distance communication with short waves in accordance with this theory, AR/30

either vertical antennae of other types of antennae located at proper heights and working at the proper harmonic have been used.

The correctness of this theory has been verified by actual experiment in communication.

To start with, there are two kinds of directional characteristics an antenna can have; i.e., one has to do with directivity in the horizontal plane and the other with directivity in the vertical plane, i.e. in elevation. Directional antennae of known types belong mainly to the former kind whereas the one constructed in accordance with this invention, which will be presently explained, belong to the latter kind.

In accordance with this invention the bulk of the radiated energy is directed at some angle to the horizontal plane. This is controlled by proper positioning and phasing of two vertical antennae instead of primarily choosing the order of the harmonic, as has been done heretofore.

This method makes it simple to adjust the angle at which maximum electric energy is radiated.

The following is a detailed description of the antenna system.

In Fig. 1 straight lines a n_1 c and a'n_2' c' respectively, indicate vertical antennae A and B. These antennae are parallel to each other and are spaced distance D apart.

AA/37

The curved lines a b c d and A' B' C' D' indicate the distribution of oscillating current in the antennae. n_1 and n_1' are positions of current loops. The phases at n_1 and n_1' are reversed (opposite). The straight line n_1 n_1' makes an angle with the plane perpendicular to the antennae A and B and this angle is θ. It is clear that in this case the combined electric field produced by portion a c of linear conductor A and portion a' c' of linear conductor B is greatest within the plane containing the two antennae and least within the plane perpendicular to the antennae.

If the plane of the antennae is made to coincide with the vertical plane of the earth's globe, then the electric field will vary with altitude above the horizon; that is, the field in the direction of straight line n_1 n_1' which connects two corresponding points on portion a c of antenna A and the other on portion a' c' on antenna B is greatest as the distance between the two points approaches a half wave-length of odd multiple thereof. Certainly, the electric field located in the direction of the straight line which connects the two points becomes weaker as the distance between them approaches one wavelength or a multiple thereof.

Since electric current at loop n_1' along antenna B is in the same phase as the current at loop n_1 along A, it follows that the distribution of electric field in the vertical

AA/38

plane and in direction $R_1 R_2'$ behaves in a manner exactly opposite to that described above; that is, when the distance $R_1 R_2'$ approaches a half wavelength or odd multiple thereof, the field is least, and it is greatest when that distance approaches an integral number of wave lengths.

In the light of these facts it appears that when distance $R_1 R_1'$ reaches either half wavelength or an odd multiple thereof, the electric field in the direction of the straight line $R_1 R_1'$ is greatest and, therefore, the energy of the electric wave is maximum at this elevation while lying within the vertical plane.

The Relation between angle θ, which is important in the construction of directional antennae in accordance with this theory, and the distance D between the antennae may be stated as follows:

$$D = \frac{\lambda}{2} \times 2 \times \cos\theta \qquad (1)$$

In the above formula;

λ = the wavelength used. When the phase difference between the antennae A and B is not π radians, as in the ordinary case but is: $2\pi(N + \frac{1}{n})$ radians, the following equation must be used:

$$D = \lambda(N + \frac{1}{n}) \cos\theta \qquad (2)$$

provided N and n represent positive integral numbers. In formula (1) when θ = 0, a special case, the distance between

the antennae become equal to an odd number of half wavelengths. This kind of directional antennae have been widely known.

What this inventor desires to secure by this patent are points other than those already known. Therefore, the main point of this invention relates to the method of effecting high angle of radiation of electric waves by means of a special arrangement of antennae. When θ is zero or close to it the application of this invention does not produce much effect. On the other hand, with the exception of cases where the angle is small, this invention makes possible the securing of effective results in high angle radiation and I desire to secure a patent for this.

In order to test the results obtained by means of this invention at Hiraiso, Ibaragi Prefecture a system of very simple antennae for broadcasting has been erected in accordance with the theory of this invention, and the strength of reception was tested at Ochiishi, Hokkaido. That is, at Hiraiso two linear conductors A and B were erected perpendicularly to ground and a distance D apart and the vertical angle of radiation adjusted by changing the heights H_a and H_b of the two radiators and the spacing between radiators. There were four adjustments as shown in the table below. Care was taken to keep the antennae and Ochiishi all in practically the same plane. The wavelength used was 40 meters. The test was made in the forenoon during summer.

AA/40

H_a (meters)	H_b (meters)	D (m)	Altitude of Maximum Radiation	Strength of Received signal (resolving set resistance).
20	20	20	0°	0 ohms
20	16	17.3	30°	6 "
20	11.84	14.14	45°	8 "
20	8.7	10	60°	--

The final result of the test may be seen in the last column of the above table. According to the results of this experiment as the altitude of radiation increases the strength of the received signal also increases.

Although among the tests the one with the radiation altitude of 45° shows the best result under the conditions prevailing when the test was performed, this result will vary depending on the atmospheric and other conditions. In order to explain the theory clearly in the above description a case of directional antennae which are fundamentally merely two vertical linear conductors has been cited, but the theory of this invention can be applied in other instances where a combination of these linear radiators is effected. One or two examples of this kind may be given as follows:

In Fig. 3 A_1 and B_1, which are a pair of antennae, are arranged and function like A and B of Fig. 1, and A_2B_2, A_3B_3 are also paired antennae. The distances between A_1, A_2 and A_3 are equal to either half wavelengths or whole multiple

thereof or very close to these figures. Accordingly, phases of electric currents distributed on corresponding parts of each antenna are made either equal or else opposite. Thus, the radiation within the plane which includes the antennas A_1, A_2, A_3 and others can be made almost zero.

In the case of B_1, B_2 and B_3, etc., the same condition is supposed to prevail whereby the arrangement in the figure is realized.

Furthermore, a group of paired antennas when given proper distribution of current will manifest directivity not only in the horizontal plane but also in the vertical plane.

In Fig. 4 the number of antennas shown in Fig. 1 is increased within the same plane. All of the current loops E_1 E_1' E_1'' E_1''' on the various antennas A, B, C, D are located on the same straight line and θ is taken as its angle with the horizontal plane. If the distances between the neighbouring loops E_1 E_1', E_1' E_1'', etc., are made equal to half a wavelength and the phases made opposite in order, the desired effects of electric currents in every antenna will superpose in the directions of the straight line E_1 E_1' E_1'' E_1''', thereby increasing the strength of the electric wave in the same direction. The antennas C and D are not necessarily made gradually higher than the antenna A B. This is shown in Figs. 5A and 5B. In Fig. 5A the antennas A B and C D are the same antennas as the ones shown in Fig. 1. However, AA/42

1096

in this instance it is necessary to arrange both groups in proper relations so that electric fields of the antennas A B of the first group and the antennas C D of the second group reinforce each other in the direction of θ. This case is the simplest example where A and C are of equal heights while B and D are of the same height and where the relationship of position of each antenna is considered important as shown in Fig. 5B. In Fig. 6 only the same phase of current distribution on each antenna is made effective, for instance, by partly bending the part of the antenna A on which current of a certain phase is distributed and thus disabling it as a radiator, and leaving that part on which current is distributed in the same phase, and arranging in the same manner the current distribution on the other antenna B either in the same or in the reverse phase depending on the distance between the antennas A and B. If the directional method of this invention is applied to a pair of antennas thus arranged, the effect will be particularly remarkable.

In Fig. 7 a large number of antennas B_1 B_2 B_3 ... B_n, etc., are arranged in a circle around the antenna A, the distance being $\frac{\lambda}{2}$ sec θ as the radius. In accordance with the theory which has been explained above, the antennas A B are made to radiate at altitude of θ. The phases of the current on the antennas A and B are reversed. Under such circumstances it i deducible that they radiate with [illegible]

AA/43

effect at the altitude of θ in every direction around the antenna A.

In the above explanation, for the sake of convenience a special case where the phase difference of current on the antennae A B is π radians and the distance between them is $D = \frac{\lambda}{2} \cos \theta$. However, the theory of this invention applies also, in general, and when it is applied in accordance with formula (2), the same result will be obtained.

Considering Fig. 1, since the distance between n_1 and n_1' is $\lambda(n + \frac{1}{n})$, if the phase of current of the antenna A is advanced by $2\pi(n + \frac{1}{n})$, i.e., $\frac{2\pi}{n}$ against that of the antenna B, they radiate the main energy in the direction AP. This can be readily understood in the light of the foregoing explanation.

Advancement and retardation of the phase may be easily secured, for example, by having one of the antennae A B as a reflecting body. In this case the best effect of reflecting function is obtainable at $D = \frac{\lambda}{4}$ or its odd multiple or the one nearest to such figure.

SCOPE OF THE CLAIM

A directional antenna system which has been described in detail in the specification and shown in the drawings, characterized by the passage of electric waves from the transmitting station to the receiving station; distribution on each linear conductor of the fundamental antenna, erected parallel to each other, within a plane which the transmitting station AN/44

1098 892

includes, and in phase, each succeedingly having a difference of a function of integral number of 2π radians, and corresponding loops of each oscillating current are located along a straight line, which is inclined to a plane perpendicular to the main antenna, and at a slight angle. At the same time the vertical distance between the neighboring fundamental antennae is equal to the product of the length, equal to the same function of the integral number previously mentioned, and the cosine of the oblique angle, or very close to it.

<u>Additional claims.</u>

1. A device of directional antennae which is described in the scope of claims of this patent and which is characterized by having the two fundamental antennae, one of which is employed to function as the reflecting body and having the perpendicular distance between the antennae equal approximately to an integral multiple of one-fourth of the wavelength.

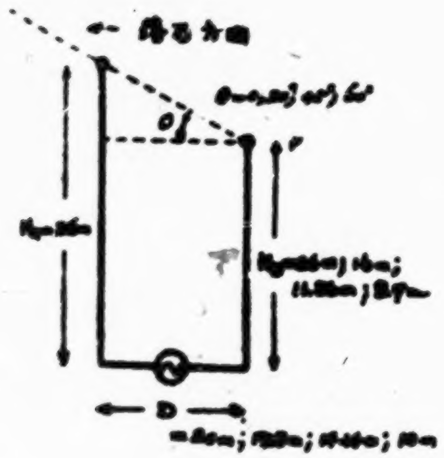
2. A system of directional antennae which is described in the scope of claims of this patent and which is characterized by having the directional antennae, composed of several multiple fundamental antennae as the element in a plane or in a plane which is perpendicular to said plane, these elements being arranged in the plane so that the action of every one is added to that of the other.

AA/HS

5. A directional antenna system which is described in the scope of claims of this patent and which is characterized by having directional antennas, composed of several multiple fundamental antennas as the element around one of which constituting a common axis the other antennas are arranged. 1A/46

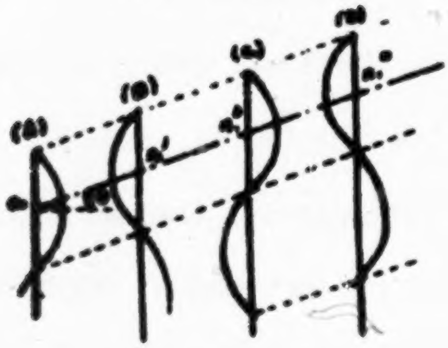
第一圖

第二圖



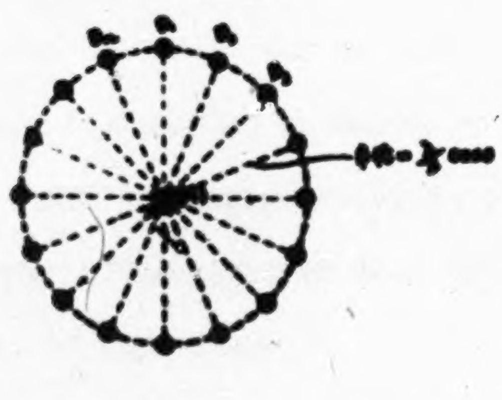
第三圖

第四圖



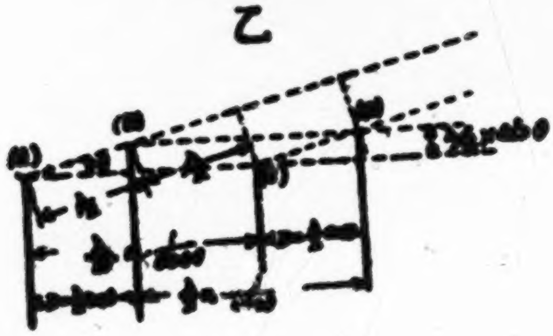
第六圖

第七圖



第五圖

乙



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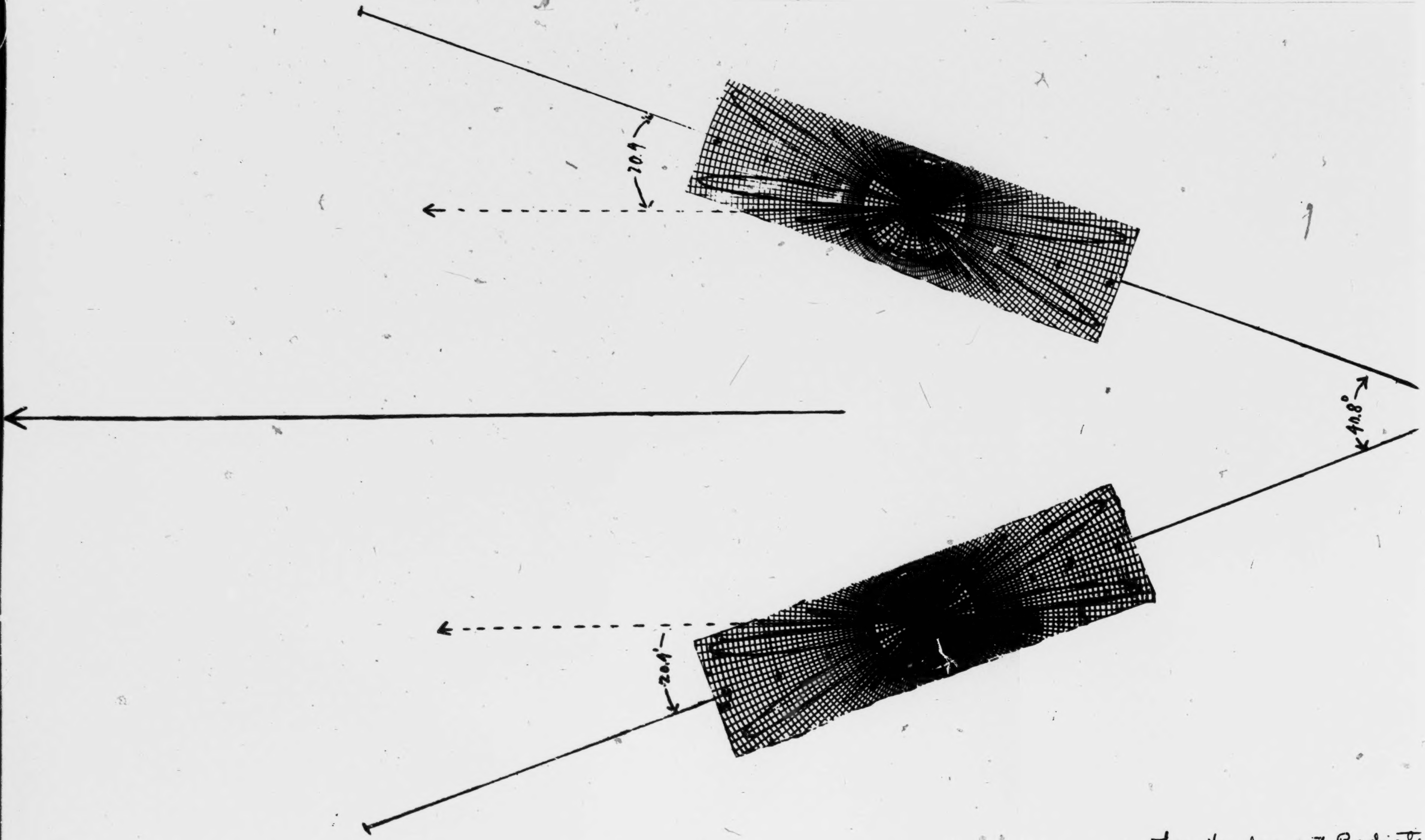
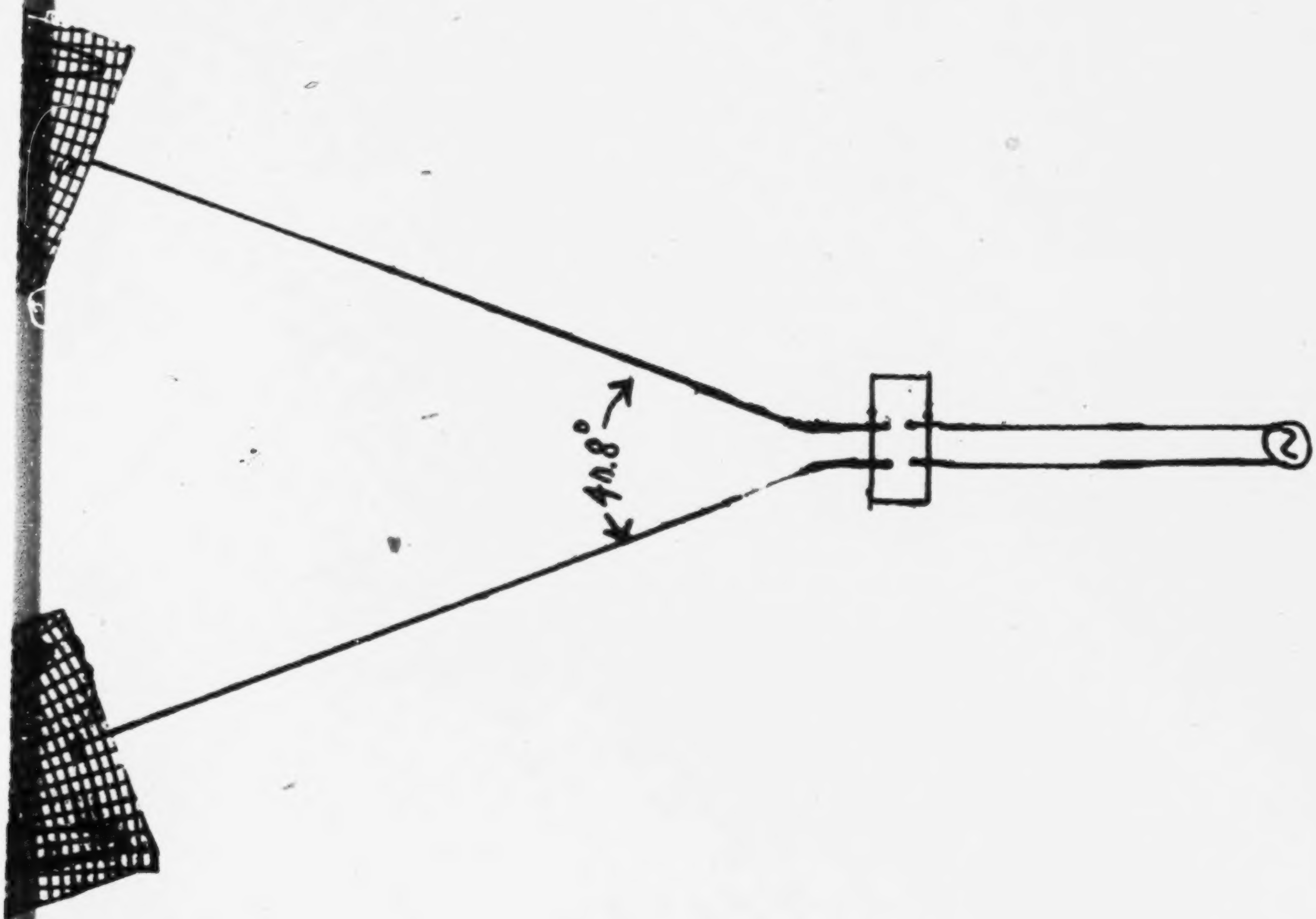


This Vee does not Radiate

Wires are 16λ

896 - 1103

DEFENDANT'S EXHIBIT BB



This Vee does not Radiate along the bisector.

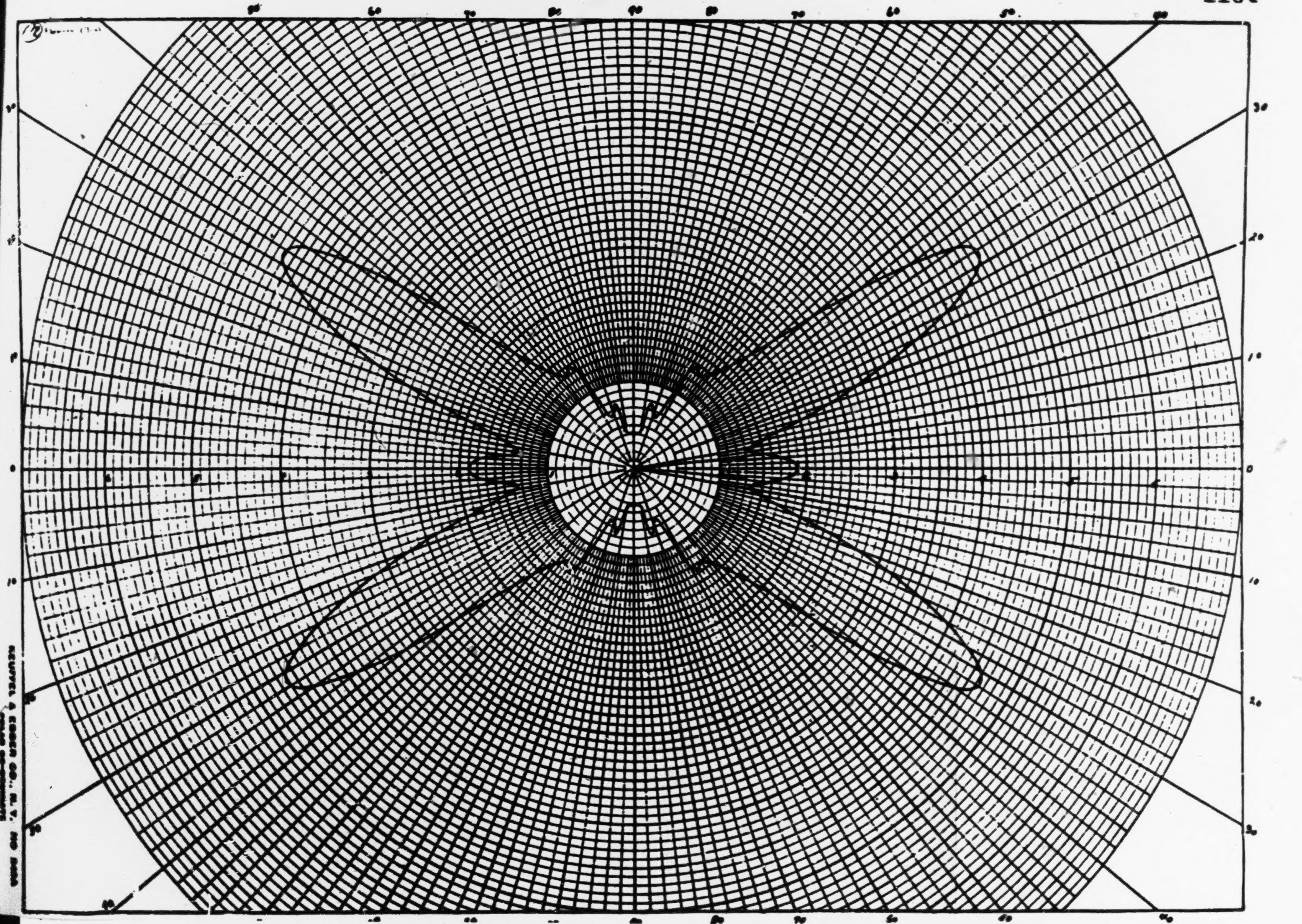
Wires are 16λ long

Radiation Pattern of V where $\ell/\lambda = 4$

Angle of V = $2 \tan^{-1} \frac{1}{10}$ = 11.42°

DEFENDANT'S EXHIBIT CC 897

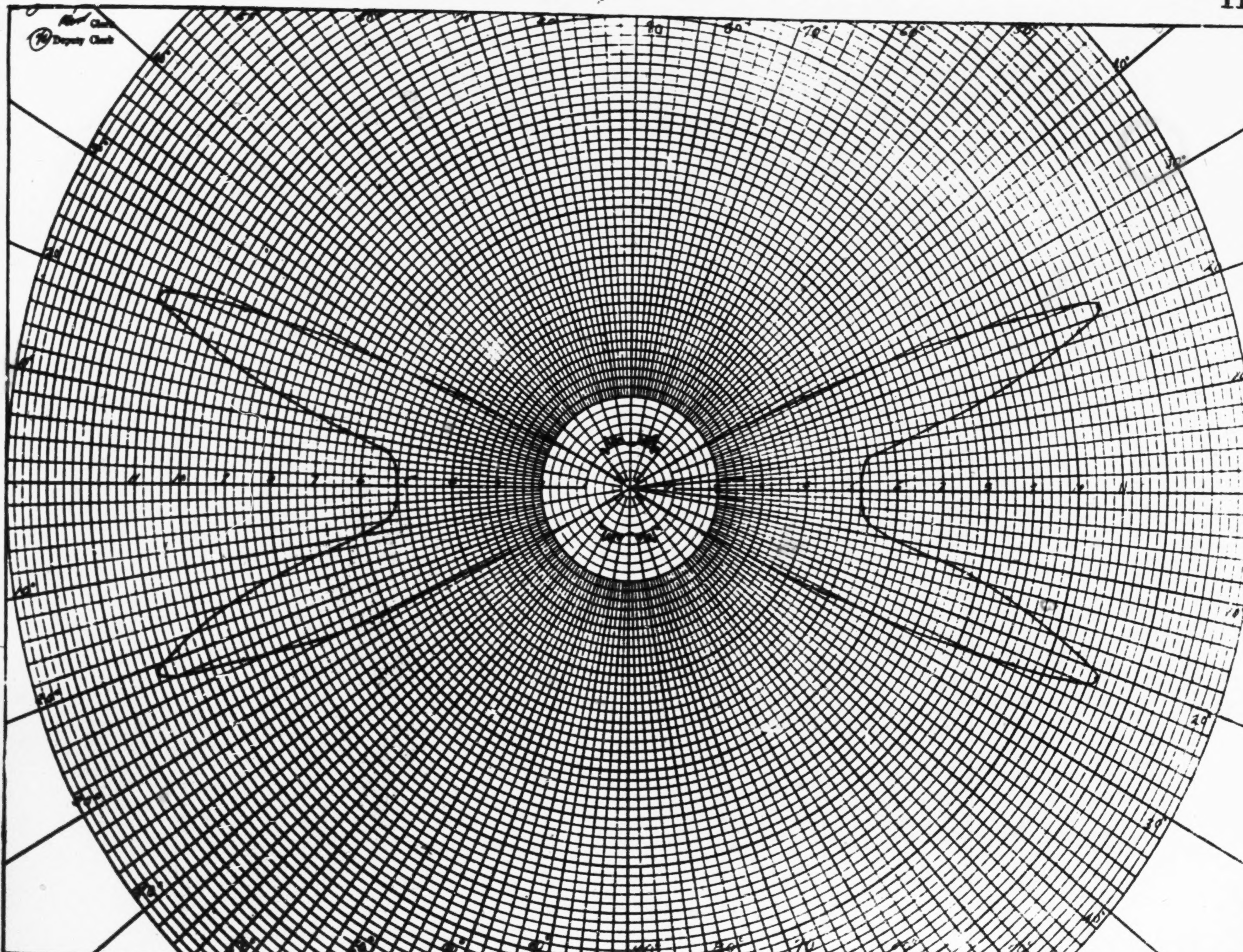
1104



RADIATION PATTERN V ANTENNA

$\frac{l}{\lambda} = 8$ ANGLE OF V = $2 \tan^{-1}\frac{1}{10} = 11.4°$

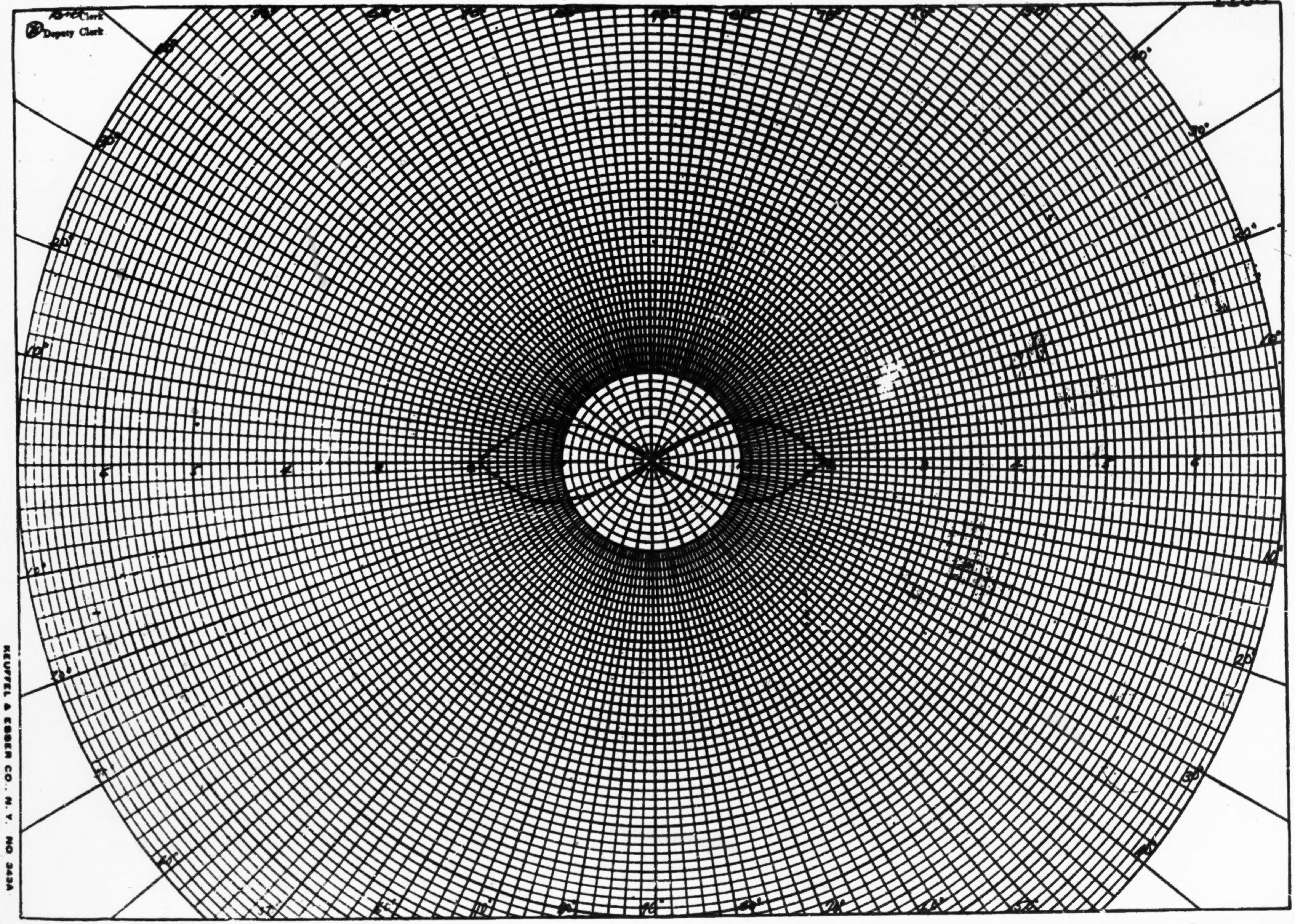
DEFENDANT'S EXHIBIT DD
1105



RADIATION PATTERN OF V IN BISECTOR PLANE
ANGLE OF $V = 2\tan^{-1}\frac{1}{10} = 11.4°$
$l/\lambda = 4$

DEFENDANT'S EXHIBIT FF

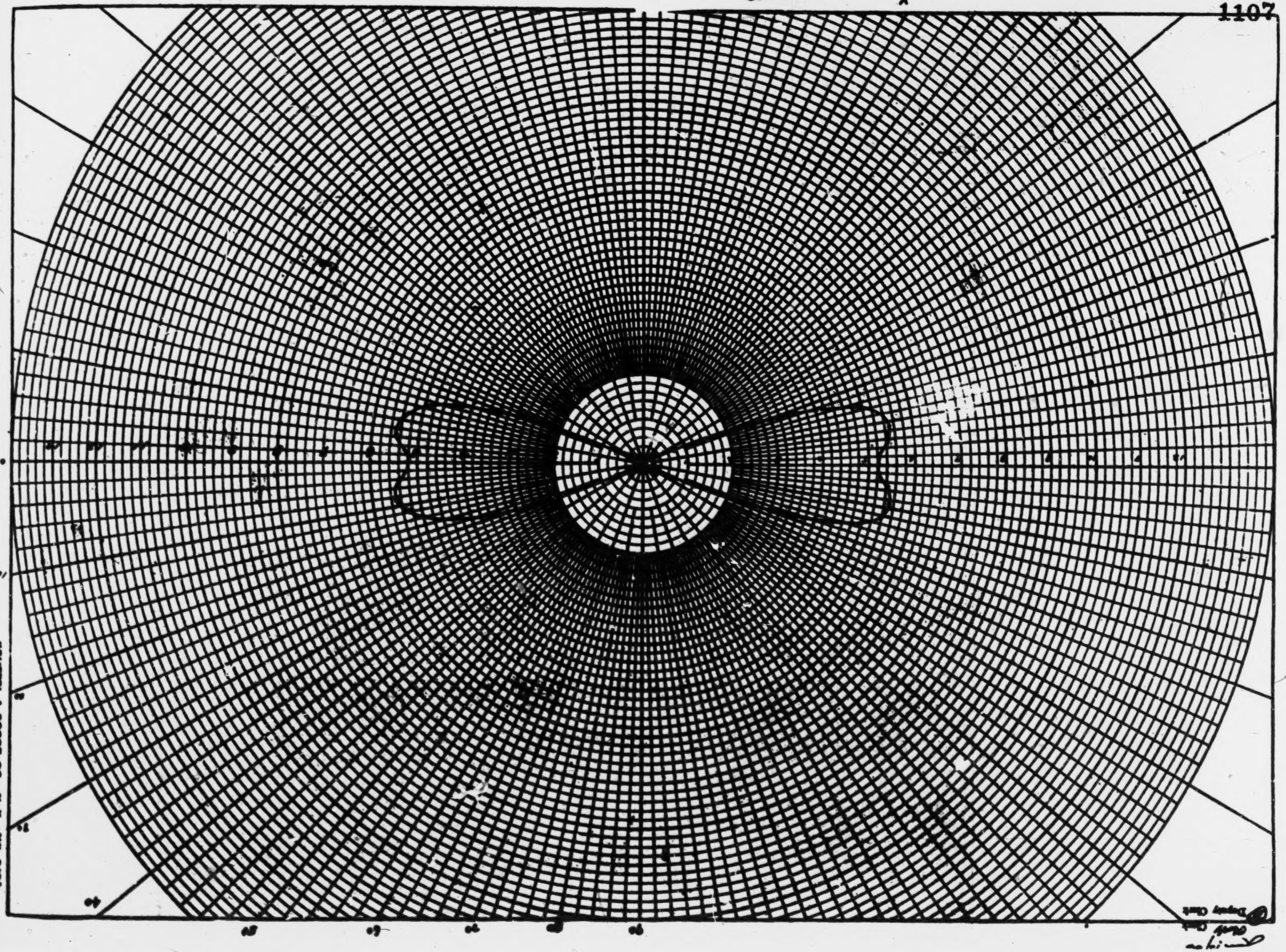
1106



Power

$\alpha = 6.71°$

Bisector Plane $\frac{l}{\lambda} = 8$

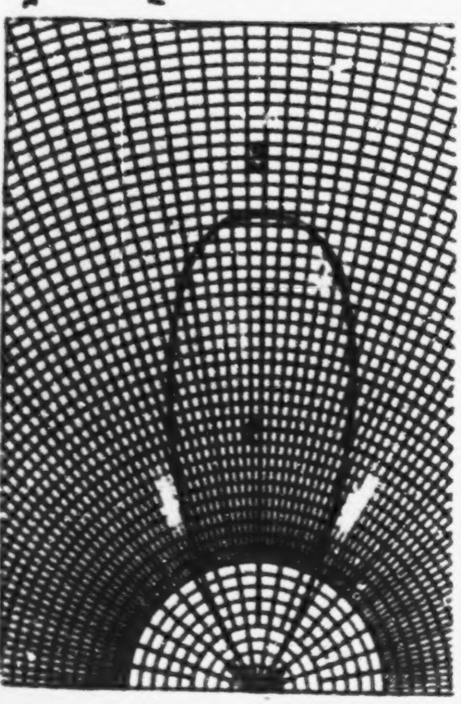


DEFENDANT'S EXHIBIT HH

ANGLE OF V - 45°

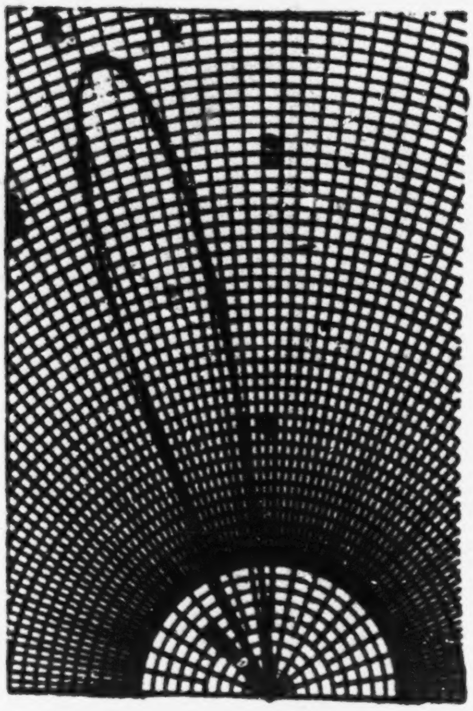
104.1%

(99.2)

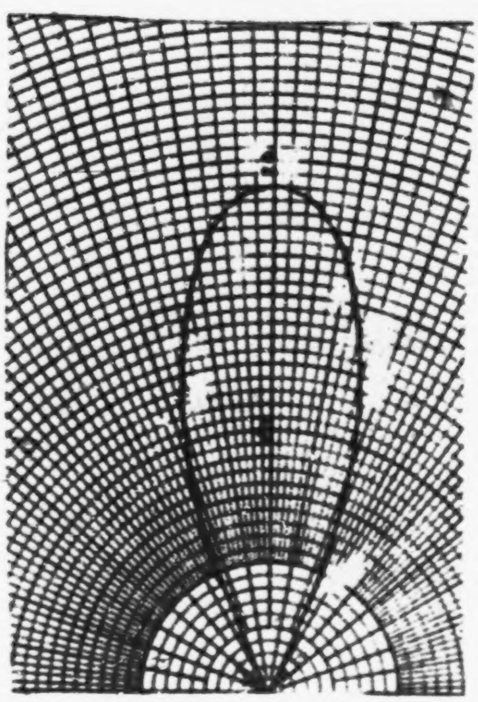


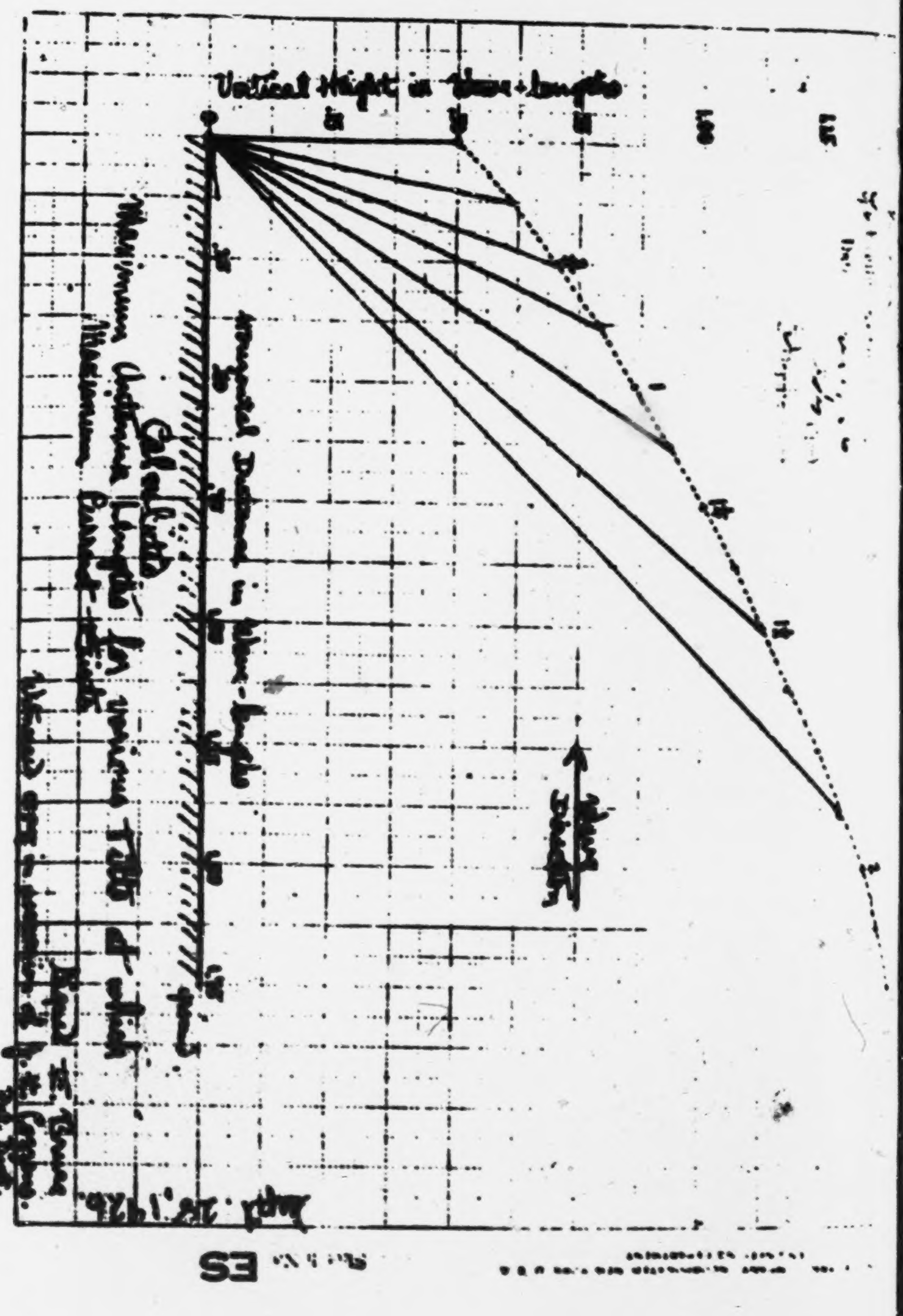
ANGLE OF V - 50°

Center
100%



(100)




Vertical Hight in Wave-Lengths
Calculated

DEFENDANT'S EXHIBIT KK

-nsity of radiation is proportional to

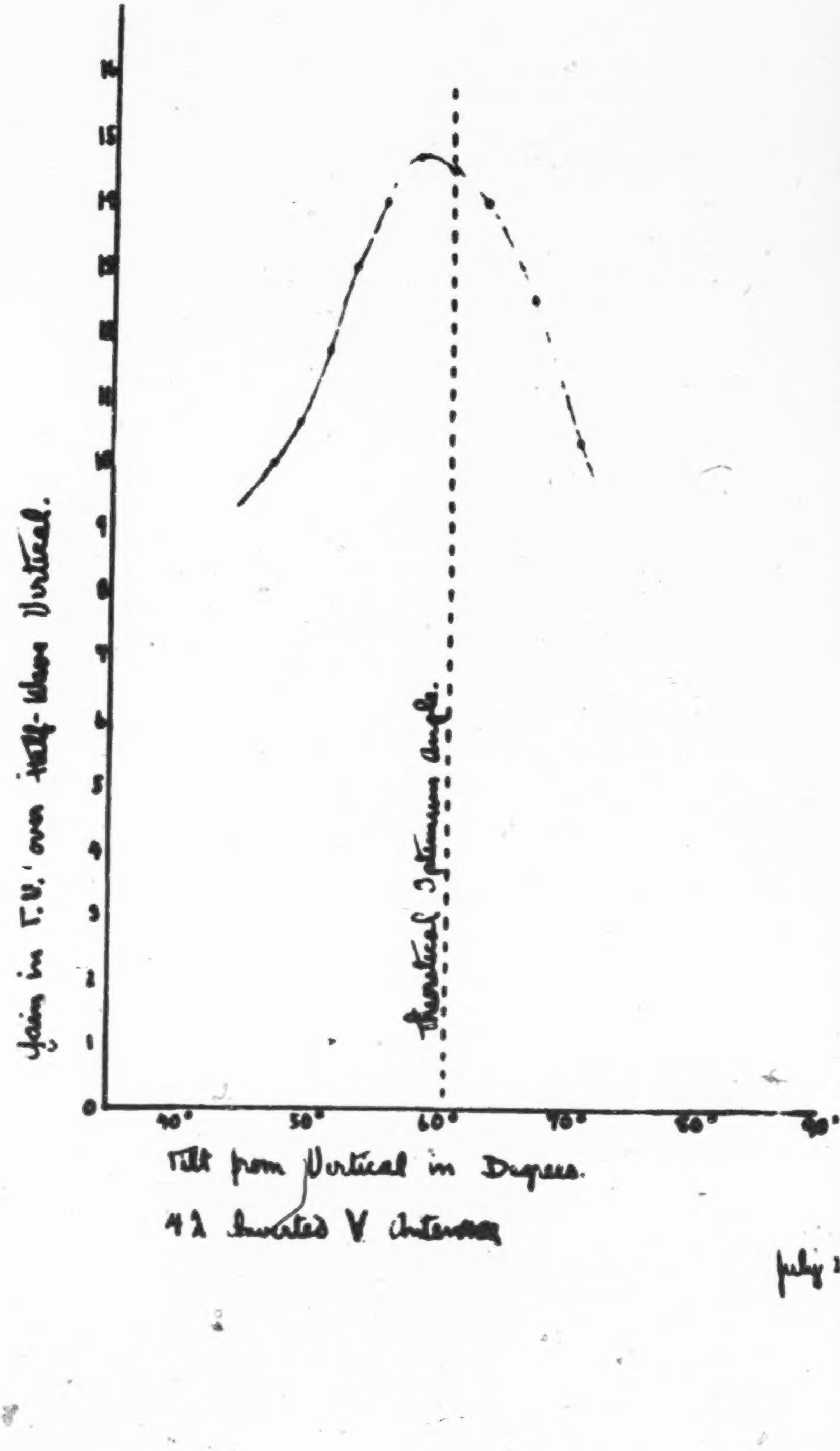
$$\frac{\cos^2\left(\frac{\pi m}{2} \cdot \cos\varphi\right)}{\sin^2\varphi}$$ for the odd numbered and

$$\frac{\sin^2\left(\frac{\pi m}{2} \cos\varphi\right)}{\sin^2\varphi}$$ for the even numbered periods

-d also,

$$\frac{\cos\left(\frac{\pi m}{2} \cos\theta_0\right)}{\sin\theta_0}$$ for odd number of half wavelengths.

Page Tightly Bound


Gain in T.V.' over Half-wave Vertical.
0
1
2
3
4
5
6
9
10
15
40°
50°
60°
70°
80°
90°
Theoretical Optimum Angle.
Tilt from Vertical in Degrees.
4λ Inverted V Antenna
July 20, 19

DEFENDANT'S EXHIBIT MM

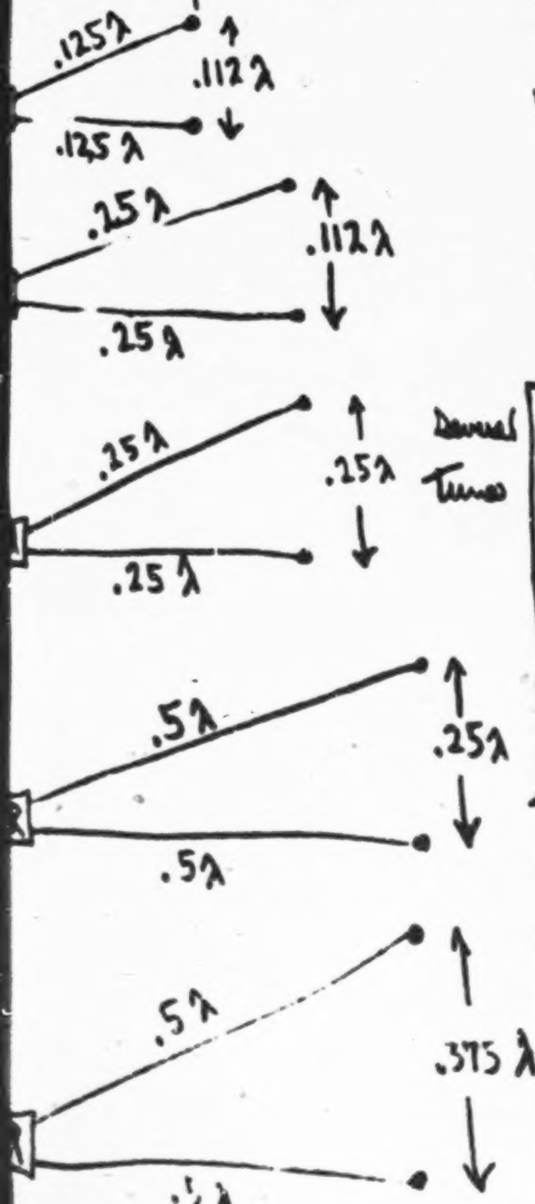
May 13, 1926.

Litton took his set back to Deal.

[The] following antenna comparisons with a loop [we]re made:

Entire test. Distant oscillator, output constant

freq. $= 12.2 \times 10^6$ $\lambda = 24.6$



Ant.		Atten for constant output	Anti resonant antenna tune: Turns of Inductance	Capacity division
Small Loop (2 turn)		10	—	—
		75	2	5
		68	2	67
	Several Turns	95	1	73
		75	2	60
		75	3	52
		65	4	51
		70	2	12
		58	1	41
		75	1	40
		62	4	8

Evidences of approaching resonance beyond condenser limits when Turns = 3 and 4.

Resonance beyond condenser limits evident when Turns = 2 and 3.

Page Tightly Bound

May 14, 1926.

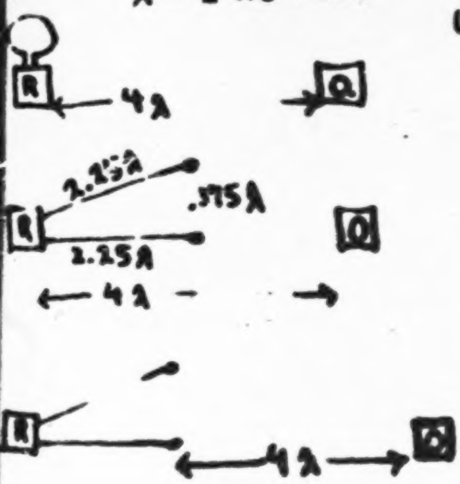
Yesterdays antenna results seem roughly reasonable according to letcher wire theory together with reappearing resonances for loads of various hyperbolic angles.

It is definitely decided that I will sail for England with Southworth and Hubbard about May 27. Telephoned to see what is necessary to get passports. Wilson recommends that I do this tomorrow

May 14, 1926.

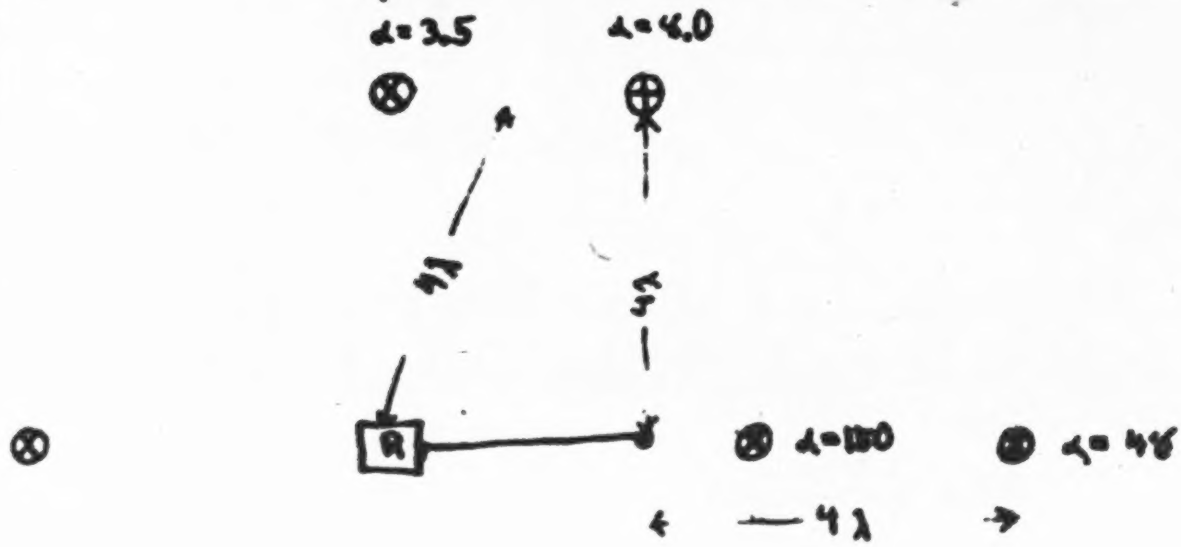
Measurement of Antenna Directional Characteristic and its comparison with a Loop Maximum as given by attenuation ratios for same output.

λ = 24.6 meters



Atten. for constant output	Anti-resonant antenna tune. Turns of L.	Cap. Divisions
10	—	—
150	1	55
150	4	20
48	1	55
48	4	20

Top View Directional Characteristic



May 15, 1926

…t to N.Y. to make application for pass ports.

Tilted Wire Measurements at Deal
on 14 meters July 19-21, 1927.

Small transmitter at a distance. Measuring set #6

Antenna Length	Output Defl.	T.U.	Optimum Coupling	Horizontal Dist. of Tilt	ϕ	TU [illegible]
$\frac{\lambda}{2}$	100	8.8	$\frac{2.5}{6}$	0'		—
λ	100	11.9	$\frac{1.5}{6}$	-19'		2.1
2λ	100	17.5	$\frac{1.5}{6}$	-57'		8.7
4λ	100	20.5	$\frac{1.5}{6}$	-150'		11.7
4λ	100	18	$\frac{1.5}{6}$	+([illegible] 150')		9.2

Note: Experiment showed that it is apparently important to avoid sagging in the tilted wires.

August 2, 1927.

Using one of the long tilted wires as an element, it is desirable to find methods of using them in arrays. Economy demands, first, studying the combinations which require only one supporting pole. The simplest scheme is shown below.

Example:
Each element = λ

Induced Voltage	→	←
Effective Voltage	→	→
Current at R		
Direct	←	←
Reflected	←	←

Note: More vector points along the wire are necessary to show this last case.
E. B. 8-8-28

It is seen that the tilts of each element are maintained the same as if they were alone. It is also seen that with the above arrangement, no radiation can take place in the YZ plane.

Signed. E. Bruce 8-2-27

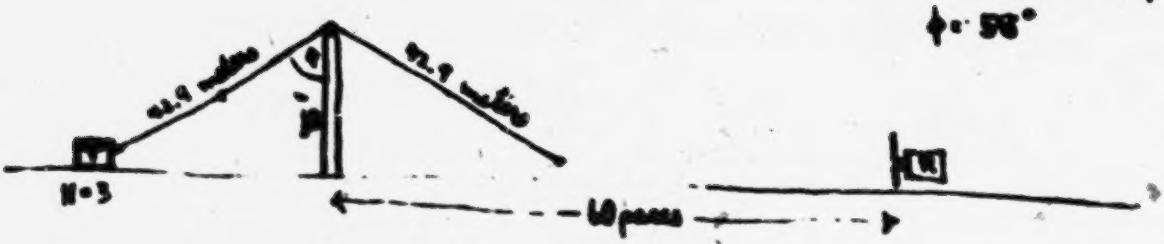
8-2-1927
H T Friis

MRV.

1119

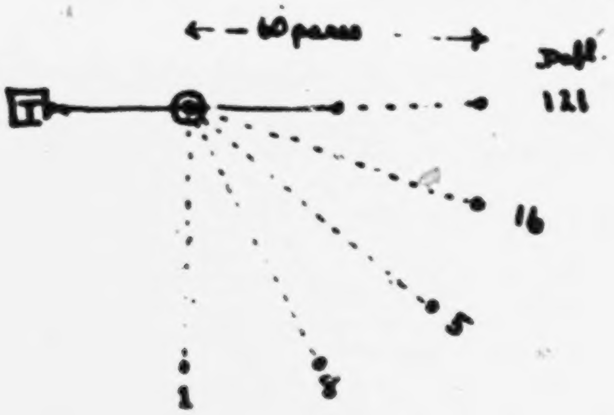
9, 1927.

42.9 meters = 141 ft.
$\phi = 58°$



Transm. Cond.	Unit. Current	Recvr Cond.	λ	Defl.		Wire length in λ.
5	.100	8	12.1	52-33 = 19		3.28
10	.090	10.5	13.3	52-33 = 19		3.23
15.	.096	13.5	13.6	60-33 = 27		3.16
20	.060	20	14.5	78-33 = 45		2.96
25	.100	26	15.6	118-33 = 85		2.75
30	.090	28.5	16.0	102-33 = 69		2.68
35	.100	35	17.1	130-33 = 97		2.50
40	.090	37.5	17.5	130-33 = 97		2.45
45	102	44	18.8	164-33 = 131	Optimum	2.28
50	.090	47	19.4	128-33 = 95		2.21

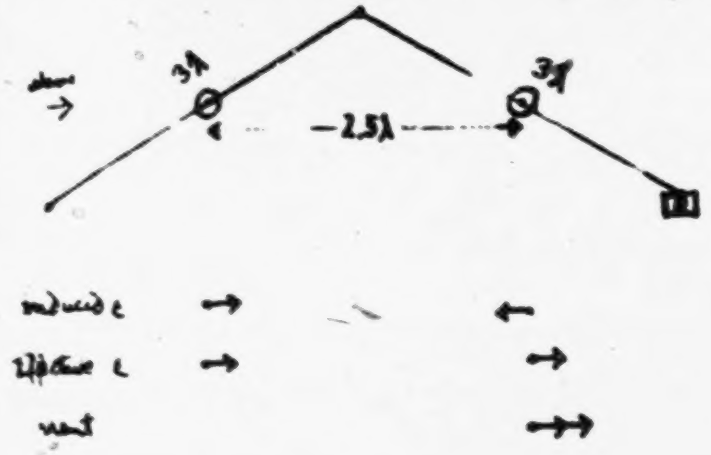
Directional Characteristic for Optimum.



Note: Theoretical ϕ for optimum L = 2.28 is $\phi = 51°$ app.

Aug. 10, 1928.

Methods of using tilted wires in combination
In order to illustrate the principles involved,
a 3λ tilted wire is used as an element.



Note: Wire distance between
a and o must be a
multiple of λ for in phase
addition

Signed E. Bruce Aug 10, 1928.

Witnessed [illegible]

March 5, 1930. (2)

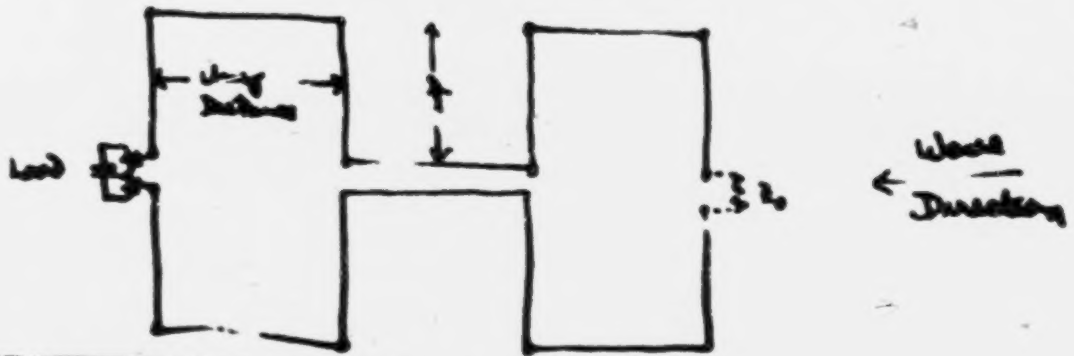
Continued

Antenna Schemes for Horizontally Polarized Waves.

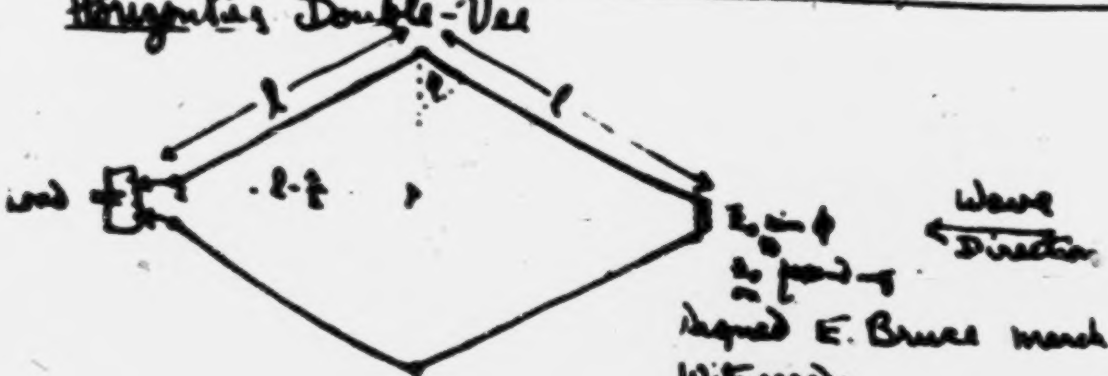
(5) Plane of Antenna Horizontal.

* Note: this distance should be preferably such that the standing waves reduce radiation. ~~Example~~: One wave-length. It is also probable that this antenna can be terminated with its surge impedance to become uni-directional.

(6) #5 in double form.



(7) Horizontal Double-Vee



Signed E. Bruce March 5, 1930

Witnessed:

[illegible]

7/25/37

Bruce

Spoke to Frus this morning about the tipped antenna that you phoned about last week

Frus was of the opinion that you were interested in dates.

According to my records my last trip to Cliffwood was Sat Oct 9th 1926. It was then that you mentioned the tipped (leaning) antenna.

J. K. Rogers

MN/9

DEFENDANT'S EXHIBIT NN

Proceedings of the Institute of Radio Engineers
Volume 19, Number 8 *August, 1931*

DEVELOPMENTS IN SHORT-WAVE DIRECTIVE ANTENNAS*

By
E. Bruce
(Bell Telephone Laboratories, Inc., Holmdel, N. J.)

Summary—Part 1 of this paper discusses the relative importance of the factors which limit the intelligibility of short-wave radio telephone communication. The more important of these factors are inherent set noise, external noise (static, etc.), and signal fading. The possibility of counteracting these limitations through antenna directivity is indicated.

Part 2 describes an antenna system which maintains a desirable degree of directivity throughout a broad continuous range of frequencies. The cost of this antenna is more favorable than that of many types of fixed frequency antennas of equal effectiveness.

Introduction

Before discussing specific antenna systems, it appears desirable to review the general problems of short-wave communication and to observe wherein antenna design can assist in overcoming existing circuit limitations. Accordingly, this paper is divided into two parts; the first will outline the requirements in the problem, and the second will be a description of an antenna system which has proved effective, despite its low cost of construction.

The writer's experience with antenna systems has been largely confined to the standpoint of reception, therefore, the following discussion will be largely on this basis. It will be apparent to the reader, however, that many of the features are likewise applicable to transmitting antenna installations.

PART 1. THE SHORT-WAVE PROBLEM

Radiotelephone Circuit Limitations

An analysis of the factors limiting the excellence of the output quality of a receiver governs the design of the entire radio circuit and associated equipment. Assuming well-designed apparatus throughout, we still encounter difficulties, especially at times of low signal strength, the more important of which are enumerated as follows:

(a) Inherent receiver noise.
(b) External noise (static, man-made noises, etc.)
(c) Signal fading.

* Decimal classification: R126. Original manuscript received by the Institute, April 28, 1931. Presented before Sixth Annual Convention, June 6, 1931, Chicago, Illinois.

The design of the receiving antenna system has an important bearing upon all three of these factors, brief explanations of which are given below.

(a) Receivers of very high gain characteristics are troubled with an inherent noise adequately described as a "hissing" sound. This may be due to several[1] causes such as shot-effect, etc. Much of this noise can be minimized through proper design, the methods of which are beyond the scope of this paper. Finally, however, an apparently irreducible minimum of noise is encountered, commonly referred to as[2] "Johnson" or circuit noise. This noise, under conditions of matched impedances, is so related to the circuit signal efficiency that the ratio of noise to signal cannot be appreciably altered except through somewhat impractical expedients such as lowering the absolute temperature of the circuit. All this tends to show that the designer of receivers must eventually rely upon his being able to increase the signal outputs from antennas to override the residual receiver noise difficulties on low field strength signals.

(b) Unpublished work, by a member of our laboratories,[3] has indicated that on many occasions short-wave static is highly directional. Interfering signals and electrical noises of human making are, of course, directional. It is quite evident that where the desired signal direction differs from that of the interference, receiving antenna directional discrimination is of immense importance.

(c) At times, remarkable reductions in short-wave fading have been achieved through extremely sharp directional characteristics of the receiving antenna. On the basis that certain types of fading are due to phase interference between multiple path signals of varying path length, it is reasonable to believe that where an angular difference exists between these paths, fading can be reduced by directivity which accepts only one of the paths. This, of course, assumes that the accepted path is stable in its direction. When this is not true, the reduction of fading through directivity becomes difficult.

The Relative Importance of the Various Circuit Limitations

The most serious hindrance to reliable, long-distance, short-wave communication is the great loss in signal fields which accompanies magnetic storms. Maintaining service under such conditions, develops into a battle against set noise and static. It is during these periods

[1] F. B. Llewellyn, "A study of noise in vacuum tubes and attached circuits," Proc. I.R.E., February, 1930.
[2] J. B. Johnson, "Thermal agitation of electricity in conductors," *Phys. Rev.*, 32, 97, 1928.
[3] K. G. Jansky, Bell Telephone Laboratories.

that effective receiving antennas are the most appreciated. The research worker on receiving antenna systems always welcomes such periods for his experimental work, since he knows well that under conditions of strong signals, a simple antenna appears to perform as well as one considerably more elaborate and expensive.

Fig. 1 will assist in comparing the relative importance of set noise and static interference. The figure is not intended to be strictly accurate as to numerical values but will convey the idea of the principles involved. There is plotted as a function of wavelength, for an arbitrary location and season, the average static voltage level delivered to the first tube of a receiver by a half-wave, vertical antenna through its

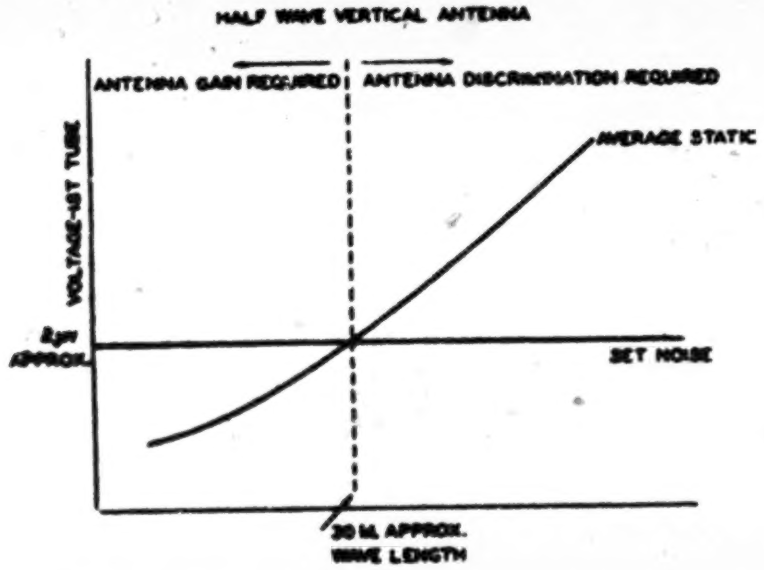


Fig. 1—Relative distribution of static and set noise with wavelength.

coupling circuits. Likewise, we have plotted the circuit noise delivered to this same tube as a function of wavelength. The fact that these curves intersect is of importance.

At wavelengths considerably below the point of intersection, a weak signal falls into the level of the set noise. Increased signal output from the antenna is desirable to override this noise. It is evident that static reduction through directional discrimination is of little use in this region, therefore an antenna having directional properties but possessing no marked gain in output over a simple nondirectional antenna has no merit. At wavelengths considerably above the point of intersection, static reduction through directivity is of utmost importance, while a gain in antenna output would be of little value if it meant a gain in static as well as in signal. It is interesting to observe, however, that a

sufficient reduction of static through directivity would lower the whole static curve until it lay below the set noise curve. Such being the case, signal gain would again be required.

The above arguments are intended to show that, at the shorter wavelengths, receiving antennas should be designed for a gain in signal output. At the long wavelengths, directive discrimination in reception is the major requirement. In contrast to this, a transmitting antenna has no such wavelength eccentricities. Its purpose is always to lay down at the receiving point as great a field as possible. We must not forget, however, that the time is near when more attention should be paid to marked directive discrimination in transmitting antennas as a means of reducing interference between congested communication channels.

While set noise and static are at times important factors in limiting successful short-wave communication, fading practically always presents varying degrees of annoyance. It is really surprising how much fading can be tolerated without radically affecting speech intelligibility, but for services such as high-grade program transmission where naturalness is also important vast improvements are required; consequently much attention has been, and is being, paid to this phase of the problem.

Increasing the Signal Output of Receiving Antennas

Under conditions of optimum output impedances, the magnitude of signal developed at the receiving antenna load is simply a function of

Fig. 2—Effects of antenna directivity.

the ratio of the effective induced voltage to the effective antenna resistance. The term effective induced voltage is used, as attention must be directed toward proper phasing, where the antenna dimensions are an appreciable part of a wavelength or more. Usually at short waves, the effective resistance is almost entirely the resistance equivalent of the reradiation losses. This resistance can be lowered through directivity, a simple example of which can be illustrated with the aid of Fig. 2.

If we can conceive of a point source of radiation at A, equipotential

radiation surfaces would be spherical in shape and symmetrically disposed around A. The field intensity at point B would be unaffected if we had some means of avoiding radiation through the unshaded half of the sphere, with a consequent saving of half of the radiated energy. If instead of saving this energy we added it to the shaded side, the energy available at B would be doubled. This is a simple explanation of the effect of directivity in the transmitting case. The receiving case is quite similar.

If the transmitter is at B, the energy available at A is diminished by reradiation losses. If we avoid reradiation through the unshaded half of the sphere, the radiation equivalent resistance is halved and the load energy will be doubled, after rematching the load to the antenna impedance.

With this knowledge of the usefulness of sharpened directivity, the designer is tempted to carry it to an extreme. The degree of directivity that may be beneficially attempted is, of course, limited by the variation in the apparent direction of wave arrival. For transatlantic, 16-meter signals over a daylight path, the horizontal plane angular variation, at New York has been[4] measured, by observing phase differences between spaced antennas, to be some 5 degrees or less, but apparently random throughout this range. Over a combination path of darkness and daylight, a horizontal angle variation considerably greater than this magnitude is frequently observed.

In the vertical plane, the variations in the apparent directions of arrival are considerable and also random. On rare occasions, angles as high as sixty degrees from the horizontal have been recorded. A sharp low angle antenna may well be expected to decrease in output as the angle of the wave direction becomes high.

Knowing that the interpretation of wave directions, by means of observed phase differences between spaced antennas, might be complicated if multiple waves of varying angles were present two vertically polarized test antennas were built having optimum response at 27 degrees and at 6 degrees from the horizontal, respectively as shown in Fig. 3-A. These angles were experimentally obtained from airplane measurements. Fig. 3-B, which has been smoothed out for publication, is characteristic of about 80 per cent of the comparative data obtained on these two antennas, as measured by automatic signal recorders. Examination will show that, very frequently, the high angle antenna increases in output as the low angle antenna loses, or vice versa, indicating that the waves are varying in their vertical angle. Similar methods

[4] H. T. Friis, "Direction of propagation and fading of short waves," Proc. I.R.E., May, 1928.

have also cross-checked the horizontal plane movements previously mentioned.

Where it is planned to design a single fixed antenna for a particular service, the antenna should be sufficiently broad in its directivity to include most of the directional variations in signal arrival that may be encountered. In such cases, we have adopted the policy of simultane-

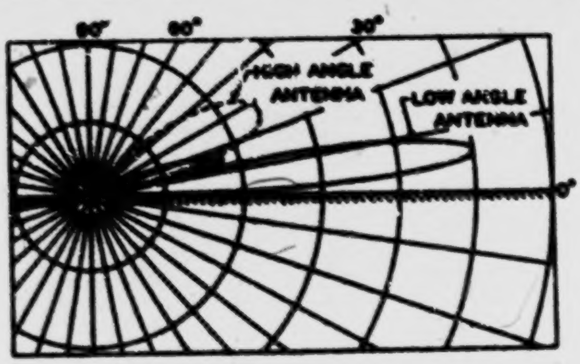


Fig. 3a—Comparative directive diagrams of a high and a low angle antenna.

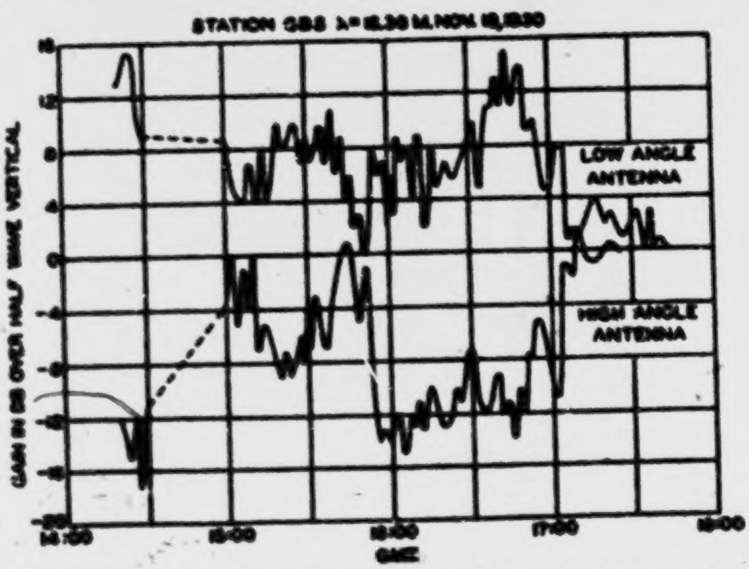


Fig. 3b—Comparison of signal outputs of a high and a low angle antenna.

ously comparing the signal outputs of various size antennas through the measurements of automatic signal recorders over long periods. A photograph of one such signal recorder is shown in Fig. 4.

Several of our test antennas have proved to be too sharp. On occasions, their output exceeded that of any of the smaller, less directive antennas, but when averaged over long intervals of time, they proved to be deficient. At first, we tried to avoid putting too much weight on

gain data obtained when signals were normally very strong but long experience seems to show that wave direction variation has little correlation with the field strength of signals.

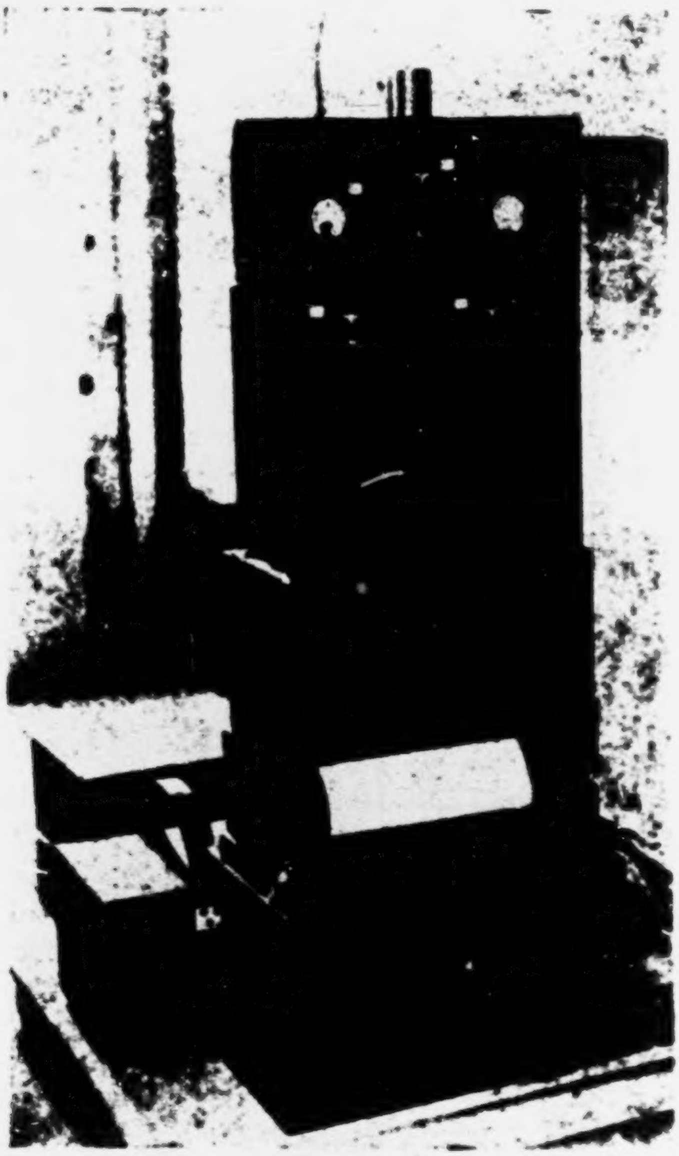


Fig. 4—An automatic signal recorder.

Static Reduction

Referring again to Fig. 2, assume that point *A*, receiving from *B*, is surrounded in all directions by static of uniform intensity. If *A* is made responsive only in the shaded directions, half of the static appears, at first, to be eliminated, but we must remember that, by previous argu-

ments, the static output from the shaded region is doubled; thus the over-all static output is the same. For uniform distribution, the static output level is independent of the degree of directivity, provided that impedance matching between the load and the antenna is always maintained. We see, therefore, that the improvement in signal-to-static ratio in this case is the same as the signal improvement alone.

If static were always uniformly distributed about an antenna, the problems of signal gain and improvement in the signal-to-static ratio would be synonymous. The fact that short-wave static is usually highly directional puts an entirely different aspect on the problem. If, in Fig. 2, the static came from a direction included in the unshaded portion of the characteristic, the improvement in the signal-to-static ratio would be infinite. In a receiving antenna, therefore, emphasis must be placed on the deep suppression of response in other than the favored direction.

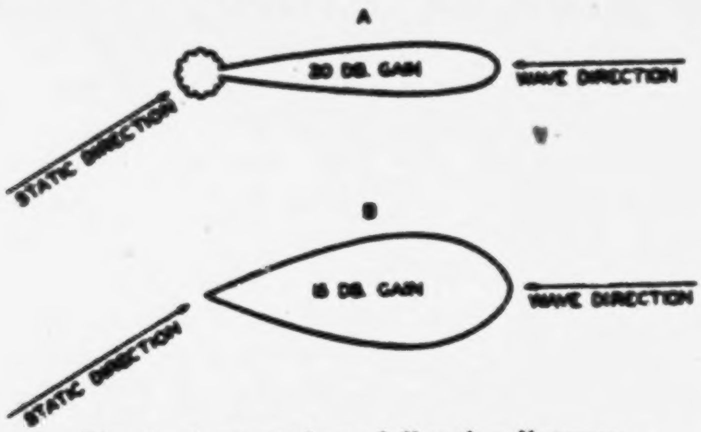


Fig. 5—A comparison of directive diagrams.

Fig. 5 is intended to illustrate the case described. The antenna characteristic 5A, having a signal gain of 20 decibels over a nondirectional antenna, does not accomplish deep rejection in other directions. It follows, therefore, that the better discriminating characteristic 5B would give a vastly better signal-to-static ratio, in spite of a smaller signal gain.

Fading Reduction

Many schemes for counteracting fading are in use and have been suggested. These include compensation for fading through automatic control of the receiver gain, the automatic selection of the best of several antennas, single side band with an unvarying locally supplied carrier, etc. All of these systems have merit, but are not a complete cure for the very prevalent selective type of fading, where several depressions may exist within a frequency band width of speech magnitude.

Under certain conditions, selective fading can be combatted through antenna directivity, but it is not without its difficulties in attainment. This is a direct attack on the multiple path source of the evil, eliminating a cause which makes fading selective with frequency. At times, very marked fading reduction has been obtained by this means.

Economics of Receiving Antennas

We have indicated briefly that the receiving antenna system has an important bearing upon all the major factors which are limitations in the present short-wave art. As long as these improvements can be effected in the receiving antenna system at a cost less than, for instance, a corresponding increase in transmitter power, concentration on the development of antenna design is well warranted

One often hears the question whether one type of directive antenna is better than some other type. The answer usually depends on an economic comparison rather than an electrical one. The sharpness of directivity, the gain, etc., are determined by existing conditions. Numerous types of antennas can be designed to meet these specifications, therefore it is evident that the final selection is often based on over-all costs.

In Part 2 of this paper an antenna system will be discussed which is the result of an attempt to produce an effective antenna at a cost more favorable than the types we have been accustomed to use up to the present time.

PART 2—LONG WIRE ANTENNAS

Types of Directive Antennas

Directive methods, employing a finite number of spaced elements of specific phase and amplitude relations, have been known for a long time. Most of the more recent innovations, in this form of antenna, have pertained to the methods whereby, in their practical applications, these phases and amplitudes have been achieved. Considerable use has been made to date of such antennas, but they are quite expensive in their larger sizes and often their frequency range is very limited. As a result of these frequency restrictions, the radiotelephone receiving station at Netcong, N. J., employs ten[6] antennas, all differing in their design frequency but having the same favored direction toward England.

For some time, it has been appreciated that if it were possible to

[6] A. A. Oswald, "Transoceanic telephone service—short wave equipment," *Bell Sys. Tech. Jour.*, April, 1930.

substitute a single directive antenna, having frequency characteristics sufficiently broad as to cover the above mentioned ten channels, a very large economic saving could be effected. Development work was undertaken which has not only resulted in an antenna of considerable frequency latitude, but this new antenna structure is actually less expensive than a single, equally effective unit of the previous type. The remainder of this paper will be devoted to a discussion of various applications of this form of antenna.

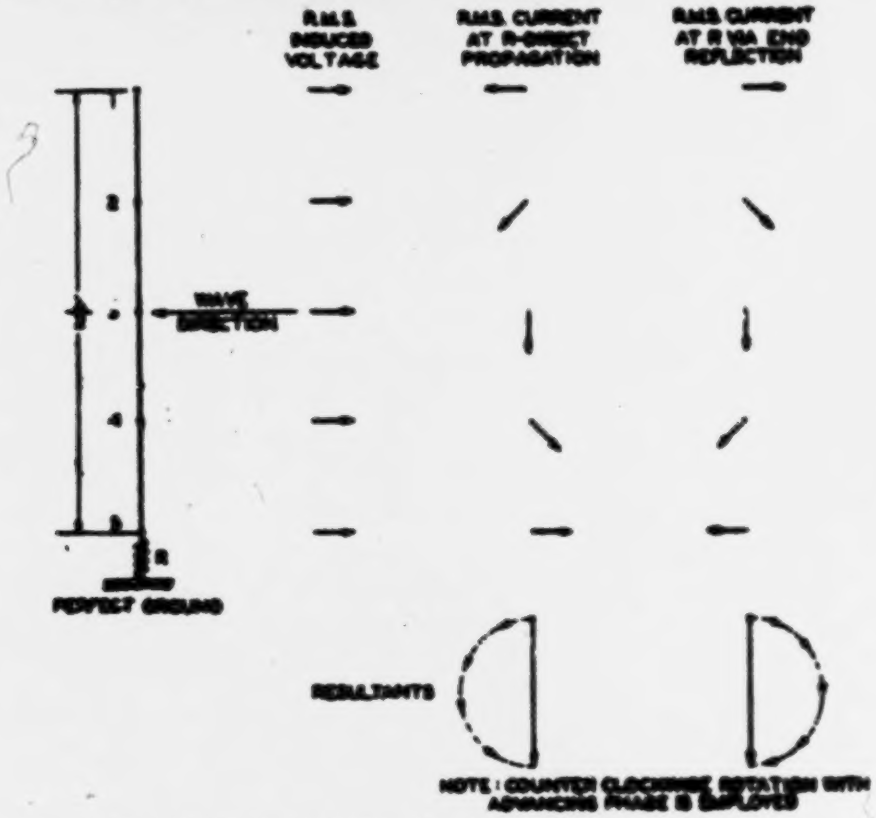


Fig. 6—Vector relations in a half-wave vertical antenna.

Principles of "Tilted" Wire Antennas

The elementary principles underlying "tilted" wires can be explained more readily by presenting a physical picture, through the use of r-m-s vector representation, rather than through a more or less cumbersome mathematical treatment. The vector representations that follow are not rigorous but they serve to convey quickly the ideas under consideration and give results which are in sufficiently good accord with the complete mathematic analysis.

As we increase the length of a simple vertical antenna exposed to horizontally propagated waves, always rematching impedances by

varying the load at its base, we obtain increases in the load power up to the point where the antenna wire length reaches one-half wavelength. The vector representation of this one-half wavelength case constitutes Fig. 6.

The first column of vectors represents the phase of the induced voltages, assumed to be lumped at points 1 to 5. The second column of vectors indicates the phase of the directly propagated currents arriving at R and due to each lumped voltage. The phase changes are due to the varying intervals of time required to traverse the intervening path.

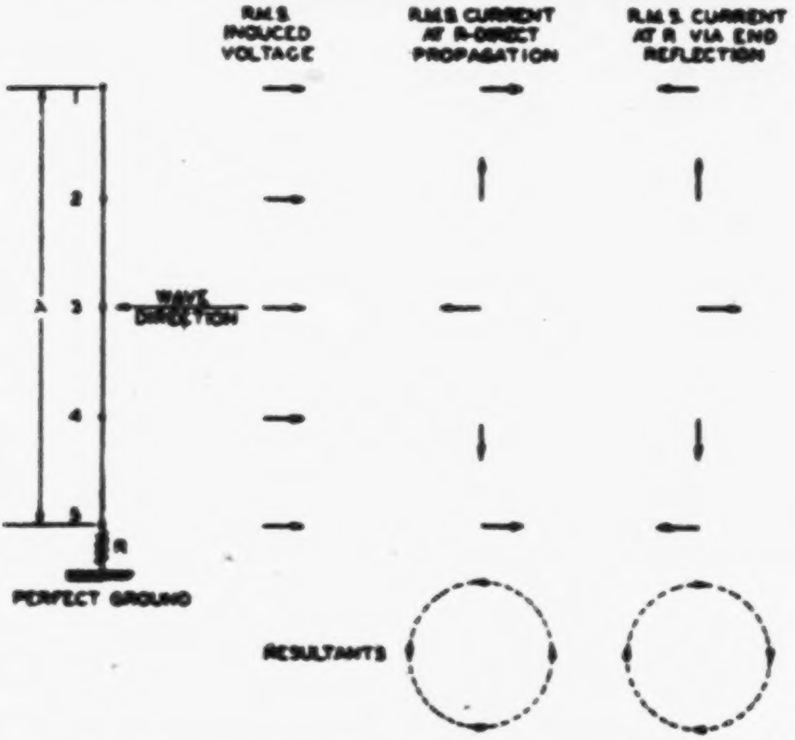


Fig. 7—Vector relations in a one-wave vertical antenna.

Likewise, the third column represents the current reaching R by way of the open-end reflection where a 180-degree phase change occurs. Summing up either column of current vectors, we trace a semicircumference and the resultant is a diameter. Had the antenna wire been slightly longer, the circumference would have been further closed and the resultant smaller. Fig. 7 illustrates an extreme case where the currents in R are zero for the vertical antenna length of one wavelength. Analyzing these vectors, we establish an important principle, as follows:

The length of a straight antenna wire is an optimum value, for currents directly propagated to the load, when the elementary currents due

to voltages induced in small lengths at the two wire extremities are opposite in phase at the load, provided that this does not also occur for intermediate points. This statement has been restricted to the directly propagated currents since, in what follows, we shall, practically always, dissipate the currents propagated to the far end in appropriate terminating impedances. In many of the diagrams, the load currents which would arrive from open-end reflections have been included merely as of general interest.

The above stated principle permits us to remedy the null situation of Fig. 7 by tilting the wire as shown in Fig. 8. Notice that point 1 has

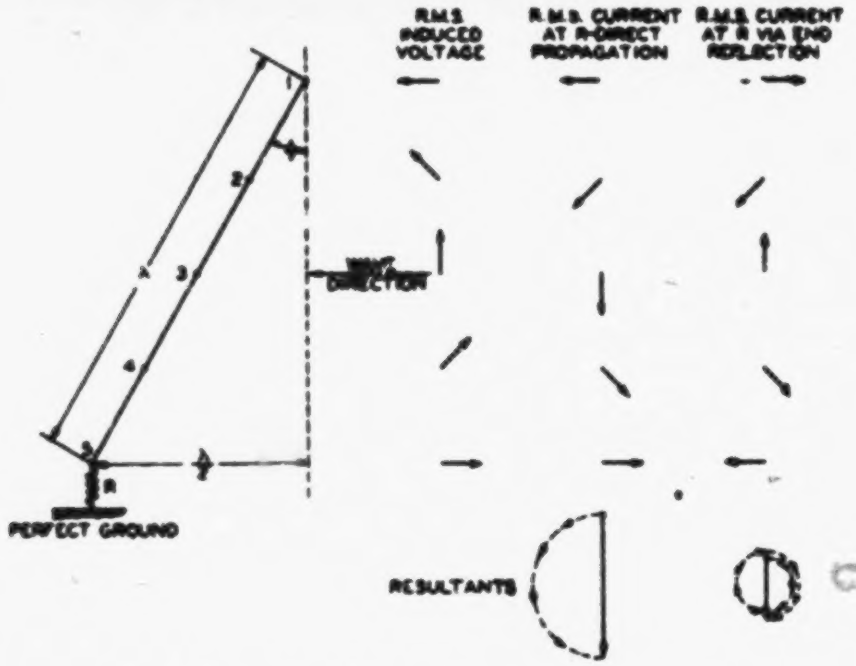


Fig. 8—Vector relations in a tilted wire antenna.

been advanced into the wave propagation so that, at any given instant, point 1 is later in phase than for instance, point 5. The directly propagated currents of Fig. 8 trace a semicircumference and, therefore, the wire length[6] appears to be an optimum for the tilt selected.

For any wire tilt angle, there exists a wire length which will trace a semicircumference similar to the above. This occurs when the tilt is such that the wire length is one-half wavelength longer than its projection upon the wave direction of propagation. Using appropriate tilt

[6] For rigid accuracy in determining optimum dimensions, a small correction must be applied to these rules. This correction occurs in cases where, upon changing the wire tilt angle, the rate of change of induced voltage is comparable to the rate of change of load current as described above.

angles, as the wire length increases, output gains are achieved through increased effective induced voltage in the wire. Still further gain in output is available through the increasing directivity that is bound to result from the increasing dimensions

One of the chief features of the tilted wire antenna is that in its longer lengths it is effective over a broad range of frequencies. This is illustrated by Fig. 9 which is a plot of the wire length versus the tilt angle utilizing the above mentioned rules. For example, if the antenna were designed for a frequency such that the wire was ten wavelengths long but it was used at another frequency where the wire length was only eight wavelengths, Fig. 9 shows that the inaccuracy of tilt angle

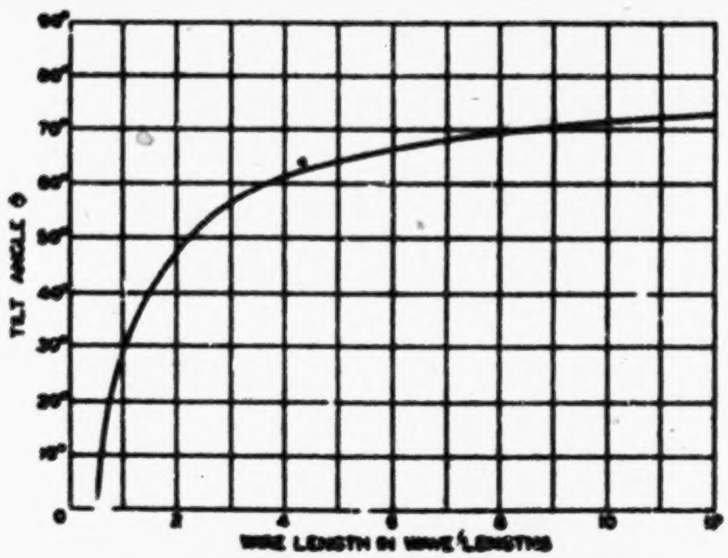


Fig. 9—Optimum tilt angle for long wires.

would be only about two degrees, which in most cases is inappreciable. As we shall see later, even this inaccuracy can be compensated by another wire in combination having an opposite trend.

Broad Frequency Range in Arrays

As is true for any antenna, the tilted wire may be used as an element in all the usual forms of arrays. Successful experimental antennas have been constructed consisting of a succession of tilted wires disposed in broadside relation, in the line of transmission and also stacked one above another. Some of these arrangements confine the effectiveness of the resulting antenna to a single frequency. Appreciating that one of the principle features of the tilted wire was its effectiveness over a broad frequency range, we have particularly stressed the development of

those combinations of tilted wires which would not place restrictions on this frequency range. One such combination is discussed in the following section.

The Inverted V

The combination of two tilted wires to form the inverted V is shown in Fig. 10. The directional characteristics are appreciably improved with a consequent increase in signal output; also, the far end of the antenna becomes accessible for termination purposes, near the ground. These terminations will be discussed later. The inverted V requires no more supporting structure than the tilted wire, therefore its additional cost is very small where the land is available. Fig. 10 is a vector picture indicating that the two elements of the inverted V add in proper phase relation.

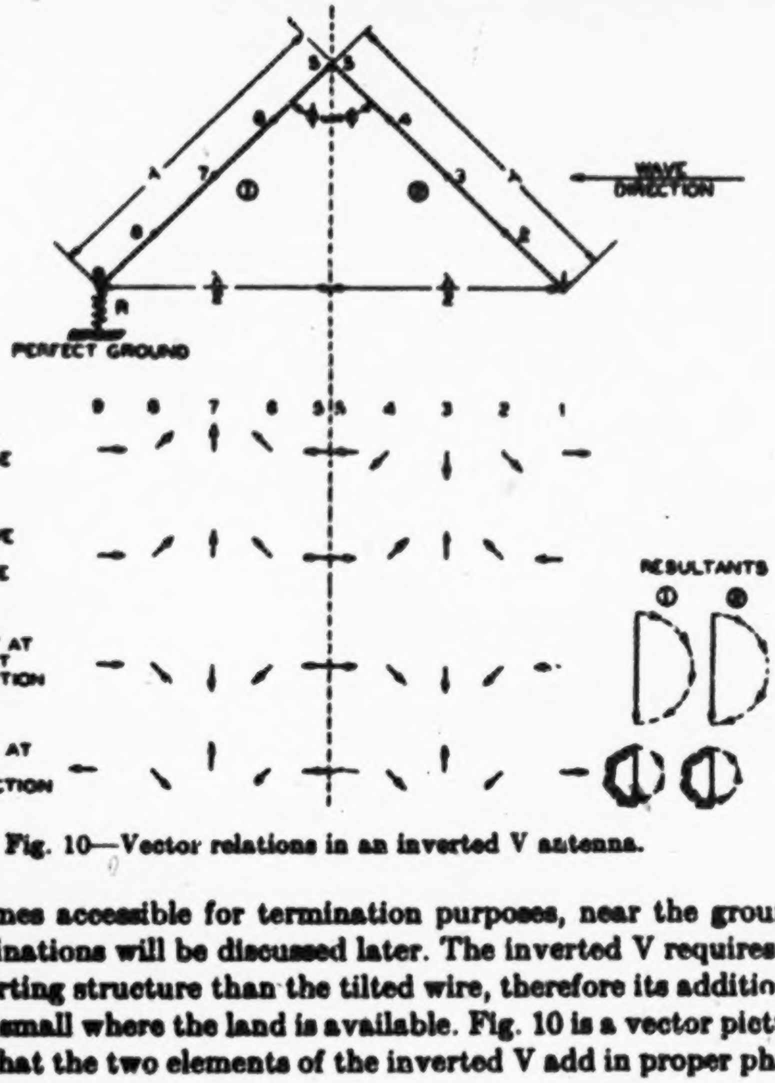


Fig. 10—Vector relations in an inverted V antenna.

In connection with Fig. 9, it has been mentioned that the small inaccuracies in tilt angle, due to departures from the design frequencies, can be counteracted by another wire in combination having an opposite trend. The inverted V of Fig. 10. is an example of one such possible

arrangement. Since the tilt angle error is opposite in direction for each leg of the V, in combination, their optimum direction of response will remain unaltered. This will be illustrated by calculated directive diagrams which will be given later.

Asymmetrical Directivity Through Far End Terminations

Where it is desired to make an antenna responsive to signals in a given direction but to discriminate against signals in the opposite direc-

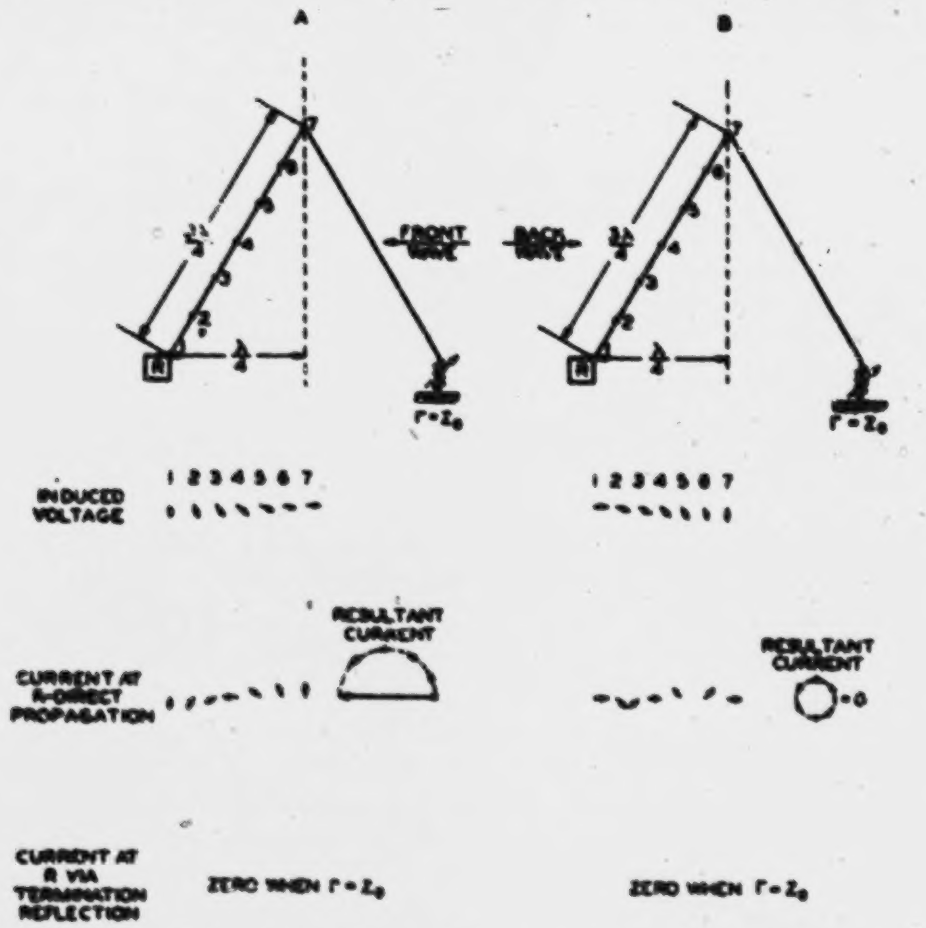


Fig. 11—Vector relations in an inverted V antenna—asymmetrical directivity.

tion, reflector systems are often employed. These reflectors may be parasitic or they may be directly connected to the receiver through apparatus controlling their phase and amplitude relations. Our experience has shown that reflectors may be employed in connection with the type of antenna under consideration for the purpose of obtaining unilateral directivity. However, the use of reflectors restricts the possible frequency range, as they only function efficiently at specific spacings in

relation to the wavelength used. For this reason, reflectors will not be discussed in this paper, although they are employed where a broad frequency range is not essential.

Tilted wire antennas and their combinations are particularly adapted to obtaining directional asymmetry through proper terminations of the end remote from the receiver. A simple example is illustrated in Fig. 11.

The end of the inverted V remote from the receiver R, in Fig. 11, is so terminated as to absorb signals without reflections. In other words, a

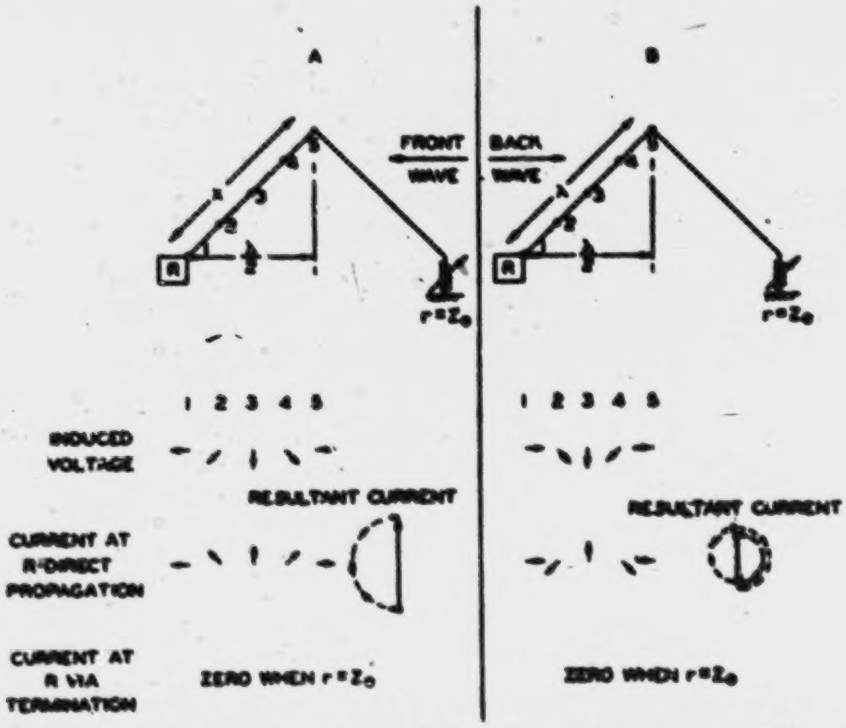


Fig. 12—Vector relations in an inverted V antenna—asymmetrical directivity.

termination equal to the antenna characteristic impedance is employed. Only the vectors for one leg of each of the inverted V's have been drawn, as the second leg is simply a reproduction of the first, and add directly thereto, after all phase relations have been determined.

In Fig. 11A, a wave from the right produces elementary load currents which trace a semicircle, as previously discussed. Note that when the wave arrives from the left as in Fig. 11B, the phase change is more rapid and a closed circle is traced making the resultant zero, thus we have achieved an infinite front-to-back ratio. It can be shown that this advantageous condition exists for tilted wires where the wire length of each element is an odd integral multiple, greater than one, of one-

quarter wavelength, provided that the previously mentioned optimum tilt, in relation to the wave direction, is maintained.

At first glance, it might appear that the frequency range is restricted, since the above rule is limited to certain wire lengths expressed in wavelengths. The most disadvantageous case exists when the wire length is an even integral multiple, greater than two, of one-quarter wavelength. Fig. 12 illustrates one such case, the wire being one wavelength long and at optimum tilt. It will be observed that the front-to-back ratio is not infinite but there still exists some directional discrimination, due to the fact that the back wave has resulted in the elementary currents tracing one and one-half rotations, thus obtaining partial cancellation. It is important to notice that longer wires would result in an increasing number of rotations and the resultant current of the back wave would become smaller and smaller as compared with the resultant of the front wave. This is a further argument for the use of long tilted wires. The calculated front-to-back ratios obtained with characteristic impedance terminations for various lengths of wires at optimum tilt are plotted in Fig. 13.

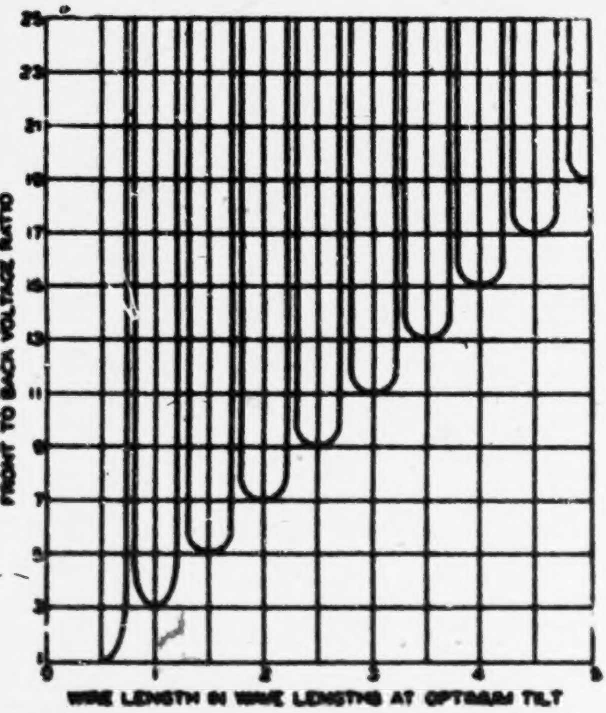


Fig. 13—Front-to-back ratios for characteristic impedance termination.

A very interesting feature about terminations is that, provided we are willing to make slight readjustments in their value, it is possible

to obtain infinite front-to-back ratios at all frequencies within range. This is accomplished by cancelling the residue of back signal by means of a small reflection from the end termination obtained by departing slightly from the characteristic impedance adjustment. It can be shown that this results, for wires which are in length an even multiple, greater than two, of one-quarter wavelength, when the termination is the characteristic impedance times the cosine of the angle made by the wire with the direction of wave propagation.

For long wires, the above readjustment is very small. As an example, a ten-wavelength wire is properly tilted when it makes an angle with the direction of wave propagation whose cosine is 0.950. Thus, only a five per cent reduction in the termination from the characteristic impedance value will give an infinite front-to-back ratio.

In practice, we usually adjust a termination to a value which is a compromise between the above value and the characteristic impedance This gives very favorable front-to-back ratios at any frequency within the range of the antenna, particularly in the case of long wires.

Theoretically infinite front-to-back ratios have been mentioned several times in the preceding discussion. It is an experimental fact that where very minute adjustments can be made in both the resistive and reactive components of the termination impedance, the front-to-back signal voltage ratio is only limited by the rigidity of the antenna elements in space. Voltage ratios in excess of 1000 to 1 are readily obtained, although such extremes are seldom warranted in practice. This deep depression can be "steered" through a considerable range of directions largely through changes in the reactive component of the termination impedance, the resistance alteration required being small. This permits a high degree of discrimination against many specific cases of interference in the rear quadrant of the antenna.

The Diamond-Shaped Antenna

In terminating inverted V antennas to ground, trouble has been experienced due to the instability of the ground contact resistance during varying weather conditions. In addition, the signal "pick-up" in the connecting leads was not always small compared with the antenna signal response in directions of antenna minima. These difficulties were avoided by terminating to the center point of a straight wire, substantially a half wavelength in total length, lying perpendicular to the favored wave direction.

As is well known, a quarter wavelength open-ended element appears to be a very low resistance when measured between its terminal and ground or another similar element. Two such low resistance quarter

wavelength elements are effectively in parallel in the above arrangement and the center-tapped symmetry substantially balances out the effect of voltages induced in these elements.

Variations of the above type of artificial ground have been used in connection with inverted V antennas but, with few exceptions, they have required readjustments as the frequency was altered. A more satisfactory arrangement from several points of view is the double-V or diamond-shaped antenna shown in Fig. 14. This provides a balanced arrangement eliminating the necessity of a "ground" connection; furthermore, it does not place any frequency limitation upon the system.

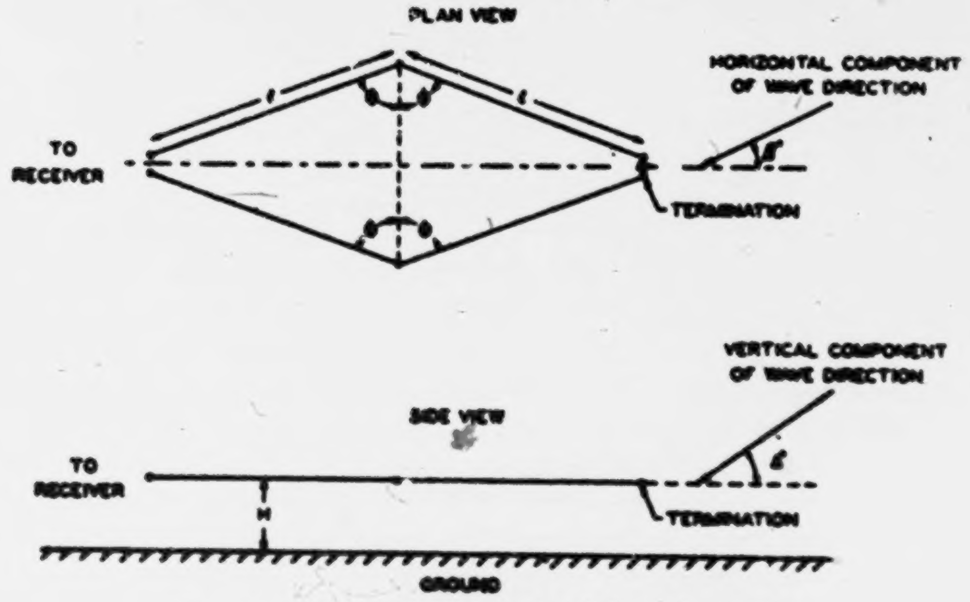


Fig. 14—The horizontal diamond-shaped antenna.

The antenna in Fig. 14 may be used with its plane either vertical or horizontal, being responsive, respectively, to vertically or horizontally polarized waves. It has found its greatest application in its horizontal form, however, due to reasons enumerated below.

(a) The supporting structure in its horizontal form is less costly, since only four relatively short poles are required.

(b) The inherent high angle directive characteristics of horizontal antennas discriminate against ignition, power, and other noises originating near the ground.

(c) The solid directive diagram of the diamond-shaped antenna is sharpest in the plane of the antenna. Since the direction of wave propagation is more stable in the horizontal plane, it is desirable to have the plane of the antenna horizontal.

(d) The directivity of the horizontal diamond-shaped antenna can be aimed, to some extent, at the most desirable vertical angle merely by altering the "tilt" angle ϕ of the antenna.

(e) The performance of the horizontal antenna is stable with varying weather conditions, since horizontally polarized waves are less affected than are the vertical by varying ground constants.

The use of the antenna horizontally, in the usual short-wave range, assumes that the strength of horizontally polarized waves are at least as great as are the vertically polarized components. Several observers have reported them more so, but the experience of the writer has been that there is little choice where horizontal and vertical antennas, having the same degree of directivity and optimum direction, are compared.

Up to this point in this paper, the attempt has been made to present simply a broad picture of some of the applications of long tilted wires to antenna design. It now seems worth while to give in somewhat more detail a sample of the design methods employed and the performance measurements on one typical form of antenna; accordingly a medium size horizontal diamond-shaped antenna has been selected.

The Horizontal Diamond-Shaped Antenna

In calculating the directive diagrams of the horizontal diamond-shaped antenna, the antenna wires have been assumed to be without resistance. As long as we are contented in knowing only the relative shape of the directive diagrams, this approximation is quite accurate and results in a tremendous simplification of the problem.

In all of the calculations, a perfect ground has been assumed. Fortunately, for horizontally polarized waves, variation in the ground constants do not radically affect either the amplitude or phase of the ground reflections, so that the following equations can be used as rough approximations even where imperfect ground conditions are encountered.

Vertical Plane Directivity

The vertical plane directivity of the horizontal diamond-shaped antenna is determined by three factors, i.e., the length of each leg, the "tilt angle" and the height above ground.

For the cases where the element length is an integral multiple of a half wavelength and where the far end termination is the characteristic impedance multiplied by the sine of ϕ (see Fig. 14), the equation for the vertical plane directivity over perfect ground has been calculated to be,

$$I_R = k\left[1 - e^{-j4\pi H \sin\Delta/\lambda}\right]\left[\frac{1+\cos\Delta}{1-\sin^2\phi\cos^2\Delta}\right]\left[1 \pm e^{-j2\pi l \sin\phi\cos\Delta/\lambda}\right];$$

where, as shown in Fig. 14,

H = height above perfect ground in wavelengths.
Δ = wave angle from horizontal in the vertical plane
ϕ = tilt angle of elements.
l = element length in wavelengths.
k = proportionality factor.
I_R = receiver current.

Note: In the third bracketed quantity use, in the $\pm$ sign, $-$ when l is an even integral multiple of $\lambda/2$ and $+$ when l is an odd integral multiple of $\lambda/2$.

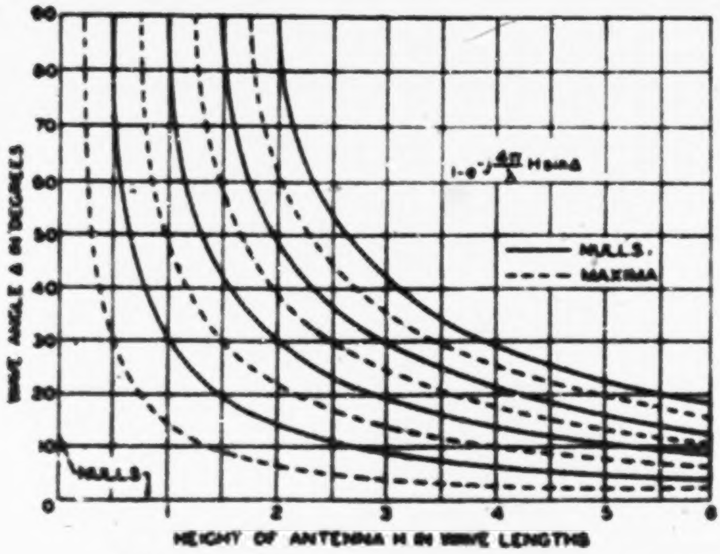


Fig. 15—Vertical plane design chart.

It will be noted that neither the length nor the tilt angle appears in the first bracketed term. It can be shown that this factor appears as a multiplier for nearly any type of horizontal antenna, accordingly the location of nulls and maxima for this factor are separately plotted in Fig. 15.

In the same manner the nulls and maxima of the product of the second and third bracketed terms have been plotted in Fig. 16 for an element length of four wavelengths.

The curves of Figs. 15 and 16 are design curves and their use can be illustrated by the following example: Measurements on the directions of wave arrival have indicated that the most usual directions are from 10 to 15 degrees above the horizontal. It is desired to construct a hori-

zontal diamond-shaped antenna for this reception, employing four-wavelength elements. Fig. 15 indicates that the most economical pole height for 15 degrees is approximately one wavelength. Now referring to Fig. 16, we see that the largest tilt angle, to accomplish this, is about

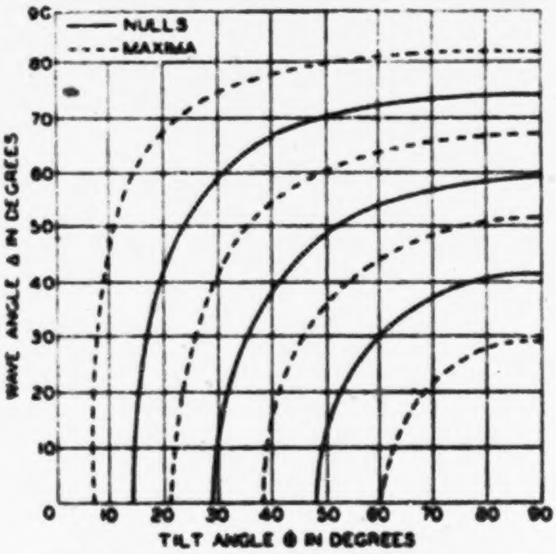


Fig. 16—Vertical plane design chart.

65 degrees. It is always desirable to use the largest possible angle of tilt to obtain the use of the largest lobe of the directive diagram.

Figs. 15 and 16 likewise give us the null points. These are seen to be 0, 30, and 90 degrees in Fig. 15 and 34, 57, 74, and 90 degrees in Fig. 16.

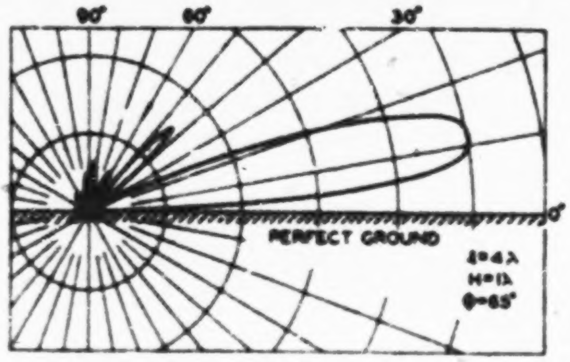


Fig. 17—Vertical plane directive diagram.

Using the above determined dimensions, the complete directive diagrams are calculated to determine whether a satisfactory result has been accomplished. Fig. 17 is the complete vertical plane diagram as calculated from the previously given equation. Should some undesir-

ably large minor lobe be present, it is often possible to suppress it by slightly changing one of the variables. A knowledge of the location of the null points, as given by Figs. 15 and 16, is a valuable guide in this accomplishment.

Horizontal Plane Directivity

Due to the cancellation effect of the reflections of horizontally polarized waves from a perfect ground, the horizontal plane diagram, for a horizontal antenna, is merely a point. The way to view directivity is properly in its solid form, but the calculations and plotted representations are somewhat laborious. The designer is in real need of knowing the horizontal width of the major lobe of the directional characteristic as would be seen from a plan view. This angular width, as measured between null points, is not altered by ground effects; therefore a useful simplification of the calculations may be had by ignoring the cancellation effect of the ground reflection. It should be pointed out that the amplitudes are slightly erroneous when this is done, but the null point locations are accurate. If this is done, we obtain the following equation:

$$I_R = k'\left[\frac{1+\cos\beta}{\cos^2\phi-\sin^2\beta}\right]\left[1 \pm \epsilon^{-j2\pi l \sin(\phi+\beta)/2}\right]\cdot\left[1 \pm \epsilon^{-j2\pi l \sin(\phi-\beta)/2}\right]$$

where, as shown in Fig. 14,

β = wave angle in horizontal plane.

ϕ = tilt angle of elements.

l = element length in wavelengths.

k' = proportionality factor.

I_R = receiver current.

Note: In the second and third bracketed quantities use, in the $\pm$ sign, $-$ when l is an even integral multiple of $\lambda/2$ and $+$ when l is an odd integral multiple of $\lambda/2$.

Fig. 18 is a plot similar in character to that of Fig. 16, giving the location of nulls and maxima in the same manner. In our previous example, vertical plane considerations indicated that a tilt angle of 65 degrees was desirable. An examination of Fig. 18 gives a rapid estimate of the approximate plan view of the directive diagram and Fig. 19 is the more complete plan diagram for this tilt angle. It will be noted in Fig. 18 that the lines indicating factor maxima and minima frequently intersect. This property can be utilized for the suppression of particular minor lobes of the directive diagram by a proper selection of the tilt angle.

Frequency Range

Previously, it was stated that the V form of antenna counteracts the slight tendency for a change in optimum direction when the fre-

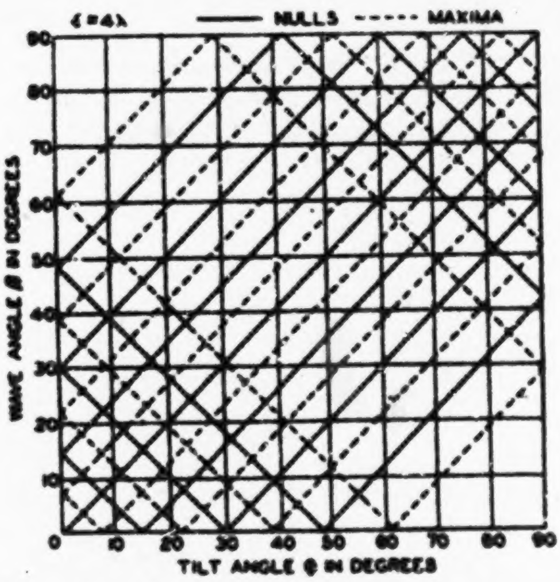


Fig. 18—Plan view design chart.

quency is altered. The correctness of this statement is verified in Figs. 19, 20, and 21. The linear dimensions and tilt angle were unaltered as the wavelength was varied over a two-to-one range. The optimum

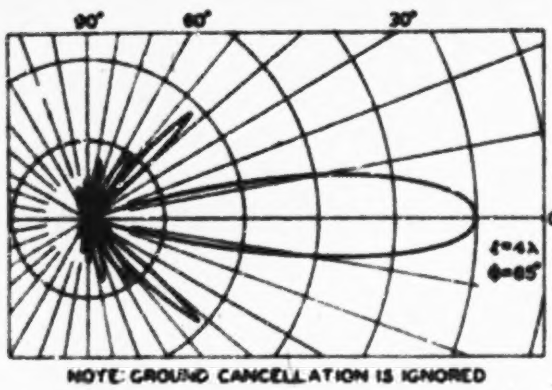


Fig. 19—Plan view directive diagram.

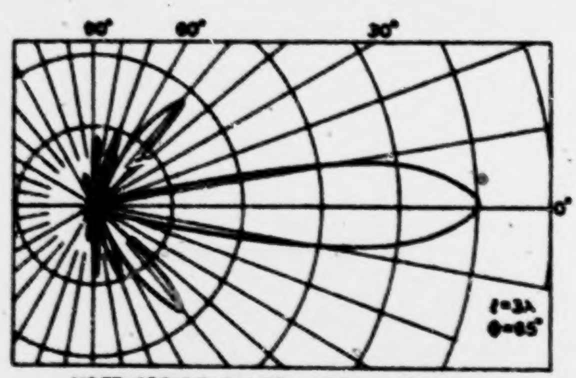
direction is maintained although, as would be expected, the directivity becomes less sharp as the wavelength is increased in respect to the antenna dimensions.

Due to the variability of the wave directions in the vertical plane, this desirable direction is not well defined. As the wavelength is in-

creased, a broadening characteristic counteracts the possibility of losing signal due to the optimum direction of the characteristic moving slightly upward.

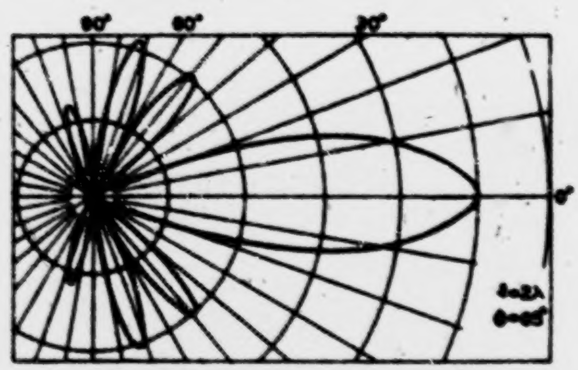
Antenna Coupling Circuit

A two-wire transmission line has been used as the connecting link between the antenna and the coupling circuits at the receiver. With this arrangement, the circuits must be carefully balanced against ver-



NOTE: GROUND CANCELLATION IS IGNORED

Fig. 20—Plan view directive diagram.



NOTE: GROUND CANCELLATION IS IGNORED

Fig. 21—Plan view directive diagram.

tical waves to obtain local noise reduction and to avoid reradiation losses from the transmission line. This is not difficult for a single frequency but if the coupling circuits are to maintain this balance for a range of frequencies, very careful designing of the coupling circuits is required.

The present practice is to place these coupling circuits in an elevated position directly at the antenna terminals to reduce the necessity for finical balancing adjustments. These circuits are connected to the receiver through a concentric pipe transmission line with its accom-

panying low loss, freedom from "pick-up," and substantial weatherproof construction. Multipeaked coupling circuits have been devised so that no readjustment is required over quite a frequency range.

Measured Performance

From the inception of our short-wave experience, we have been accustomed to compare the performance of antennas with a half-wave vertical antenna. The lower end of this standard of comparison is near the ground and connected to a coupling circuit in such a manner that matched impedances are realized. Although the antenna under consideration is intended for the reception of horizontally polarized waves, the same vertical comparison standard has been maintained.

As previously mentioned, automatic signal recorders of the type shown in Fig. 4, are connected to each antenna. This recorder indicates an integrated average signal during each ten-second period, thus removing the wide amplitude excursions due to fading. It is an interesting fact that, although the instantaneous fading of two antennas may be different, the average signal over ten seconds usually has corresponding rises and falls in amplitude. This effect is so marked that any possible inaccuracies in the timing axis are readily detected, when comparing records. To promote accuracy in amplitude comparisons, only corresponding peaks or hollows of the curves are used. It is obvious that the employment of steep sides of curves would put a premium on very accurate timing. The relative timing of recorders is usually very good, as their synchronous motors are run by the same a-c power supply. The relative signal strength accuracy of the recorders is better than one db.

The antenna reported in the following data is an experimental antenna, at Holmdel, N. J., shown in the photograph of Fig. 22. This picture illustrates the extreme simplicity of this type of antenna. The antenna dimensions are the same as those in the previously discussed directive diagrams when used at 16 meters. As has been said so many times before, the gain of the antenna over the standard may be expected to vary with the varying wave directions. The following data are the results of several hundred hours of tests, made at Holmdel, N. J., during the fall and winter months. Three different wavelengths were used with no alteration whatever in the antenna, its termination, or its transmission line coupling circuits. The standard of comparison, however, was always a half wavelength for the signal under test. It has been thought desirable to plot the gain data as the percentage of total time the antenna gain was above the indicated value in order to show the gain distribution with time. This summary of gains is given in Fig. 23.

I am indebted to a member[7] of our laboratories for an interesting variation which has been used in the application of this type of antenna to the transmitting problem. A simple terminating resistance is often

Fig. 22—An experimental horizontal diamond-shaped antenna.

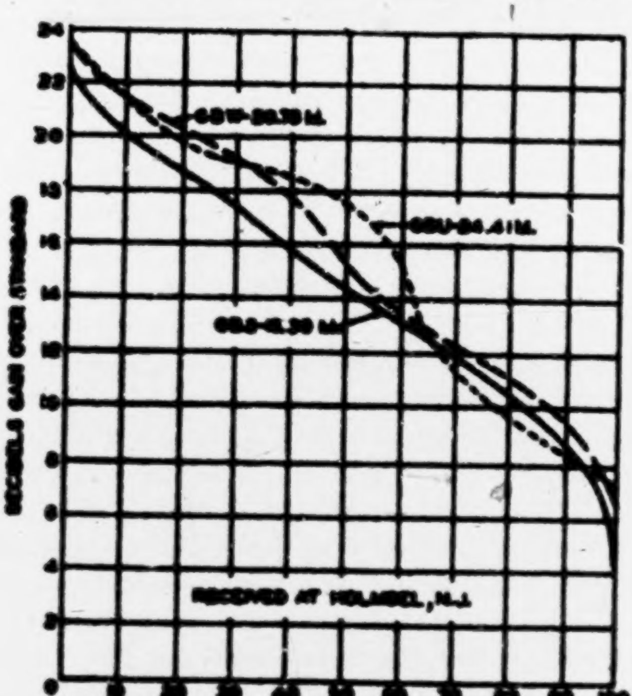


Fig. 23—Gain-time distribution curves.

undesirable in the transmitting case since it may be called upon to dissipate several kilowatts, in fact, that portion of the energy which would be radiated backward if no terminating resistance were employed. A

[7] E. J. Sterba, Bell Telephone Laboratories.

long, two-wire iron transmission line shorted at the far end has been found to be one useful terminating load of the required dissipating ability.

The terminated diamond-shaped antenna possesses a broad impedance-frequency characteristic. This property may be augmented by reducing the characteristic impedance of the antenna. One convenient scheme for reducing the impedance is to employ several conductors in parallel in each leg of the antenna. The characteristic impedance may in this manner be dropped to a value for which matching iron wire lines are readily constructed.

The terminating load which produces the most desirable impedance characteristic does not necessarily produce the best front-to-back ratio. In the transmitting case, however, the deep directed nulls required in reception, to eliminate interference of some particular station, are not necessary. It is sufficient to reduce by 10 or more decibels the field in the back directions. Thus the modified diamond-shaped antenna may be employed as a unidirectional transmitting array accepting power over a two-to-one frequency range.

In conclusion, I should like to point out that the work described in this paper was possible only through the assistance, coöperation, and advice of many people in the Bell System, to all of whom I render my sincere thanks. In particular, I wish to mention Messrs. A. C. Beck and L. R. Lowry who supervised the construction and did most of the testing of the experimental models. Mr. H. T. Friis, not only contributed many suggestions and constructive criticisms of the work, but took steps to have developed apparatus which was essential for the automatic measurement of received signal levels.

DEFENDANT'S EXHIBIT OO

Proc. I. R.E. - Vol. 14 - Oct. 1926
pp. 675-688

FIELD DISTRIBUTION AND RADIATION RESISTANCE OF A STRAIGHT VERTICAL UNLOADED ANTENNA RADIATING AT ONE OF ITS HARMONICS*

By

S. A. Levin and C. J. Young

(Radio Engineering Department, General Electric Company)

I. Introduction

Current and voltage distribution, electromagnetic field and radiation resistance are some quantities, among many, of interest in the investigation of an antenna. Their more or less complete and accurate determination is possible, mainly due to the works of H. Hertz[1] and M. Abraham.[2] The principles, given in these and other works, have here been applied to the investigation of an unloaded antenna consisting of a straight vertical wire radiating at one of its harmonics. The term "unloaded" is important. An antenna consists of a system of conductors, representing distributed capacities and inductances, which conductors are connected to one or more circuits with usually concentrated capacities and inductances. This is the general form of the loaded antenna. If the latter circuits are of negligible influence, or if no such circuits exist at all, then the antenna is unloaded.

Previously, similar calculations have been made by M. Abraham,[2] G. W. Pierce,[3] S. Ballantine,[4] H. Chireix,[5] and M. A. Bontch-Bruojevitch,[6] among others. Since the present article contains added information, its publication has been thought justified, particularly at a time when all data on short wave radio transmission are of interest.

The antenna may be grounded or not and, in the latter case, its lower end may be at any distance above ground. The in-

*Received by the Editor, January 13, 1926. Presented at the New York meeting of The Institute of Radio Engineers, September 1, 1926.

[1] H. Hertz, Ges. Werke, v. II.

[2] M. Abraham, Phys. Zeitschrift, v. 2, 1901, p. 329.

[3] G. W. Pierce, "Electric Oscillations and Electric Waves," New York, 1920, p. 135, particularly p. 181.

[4] S. Ballantine, Proceedings of The Institute of Radio Engineers, v. 12, 1924, p. 823.

[5] H. Chireix, "Radioélectricité," t. 5, 1924, p. 65. Bulletin Technique.

[6] M. A. Bontch-Bruojevitch, "Elektrotehnstvo," April, 1925, p. 228.

where n may be odd or even.
Then

$$e = \frac{4a}{cr_0}\cos\frac{2\pi}{\lambda}(ct - r_0)\cos(\beta\gamma\cos\theta)\sin\theta\frac{\cos(\beta\cos\theta)}{\sin^2\theta}. \quad (13)$$

C. *Ungrounded Antenna Operating at Even Harmonics*—Similarly, when n is an even integer

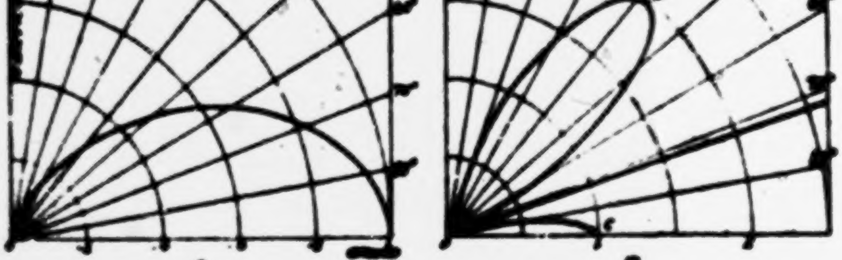
$$e = -\frac{4a}{cr_0}\cos\frac{2\pi}{\lambda}(ct - r_0)\sin(\beta\gamma\cos\theta)\sin\theta\frac{\sin(\beta\cos\theta)}{\sin^2\theta} \quad (14)$$

D. *Grounded Antenna*

$$e = -\frac{2a}{cr_0}\cos\frac{2\pi}{\lambda}(ct - r_0)\frac{\cos(\beta\cos\theta)}{\sin\theta}, \quad (15)$$

where n is an odd integer, and the limits of integration are now zero and $\frac{\lambda_0}{4} = l$.

E. *Power Distribution Curves*—The numerical value of the Poynting vector[14] is $\frac{c}{4\pi}e^2$, where e can be obtained from the equations (13)(15). Since only relative values of this vector are of interest here, the factor $\cos\frac{2\pi}{\lambda}(ct - r_0)$ may be omitted in the evaluation of e^2, as at a given moment it has the same value at all points. If in a polar diagram the length of the radius vector, corresponding to the angle θ, is made proportional to e^2, then



A B

FIGURE 5

[14] See for instance, Pierce, l. c.

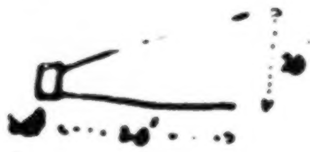
1154-1155

DEFENDANT'S EXHIBIT PP

Friday May 14 26

Fine shower in early a.m. Clearing off later. Deal ... in N.Y. with two pounds for Heising's ...

Made some calc's for Bruce. He used an antenna as



which is terminated by

and for a given freq. got several resonance settings on the anti resonant circuit.

If he has a short Lecher wire system (less than $\frac{1}{4}\lambda$) then (neglecting the manner in which the E.M.F. gets in) there will be resonance when his system is terminated by impedances which are equal to the impedance of such lengths of conductor as would make $\frac{\lambda}{4}, \frac{\lambda}{2}, \frac{3\lambda}{4}$ ---- oscillators. Or for the first two

Z_1 required

Z_2 required

and, neglecting res. and conductance

$$Z_1 = i\sqrt{\frac{L}{C}} \tan \frac{2\pi}{\lambda}\left(\frac{\lambda}{4} - l\right)$$

for all odd values of $\frac{1}{4}$ will be $\tan \frac{2\pi}{\lambda}\left(\frac{n\lambda}{4} - l\right)$

$$Z_2 = -i \frac{\sqrt{\frac{L}{C}}}{\tan \frac{2\pi}{\lambda}\left(\frac{\lambda}{2} - l\right)}$$

for all even values of $\frac{1}{4}$ will be $\frac{1}{\tan \frac{2\pi}{\lambda}\left(\frac{n\lambda}{4} - l\right)}$

And this series of impedances gives the multiple resonance phenomena Bruce observed.

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DEFENDANT'S EXHIBIT QQ

2/16/28.

Sat #7 Filter switch closed 1 button pressed

$\frac{\lambda}{2}$ Vertical coupling $= N_A = 2.5/6t$ coil

α_1 (for 80 μa change) $= 23$ TU

α_2 (" 30 - 30 μa) $= 89$ TU

$\alpha_1 - \alpha_2 = 23 - 89 = -66$ TU

Vertical Vertical
Vertical Vertical

1λ tilt (toward osc.) . $N_A = 1.5/6t$

α_1 (80 μa) $= 26$

α_2 (30-30 μa) $= 89$

$(\alpha_1 - \alpha_2) = -63$

2λ > (toward osc.) $N_A = 1.5/6t$ ~~[illegible]~~

α_1 (80 μA) $= 23\frac{1}{2}$
α_2 (30-30 μA) $= 88$
$(\alpha_1 - \alpha_2) = -64\frac{1}{2}$
} top of pole

α_1 (80 μA) $= 23\frac{1}{4}$
α_2 (30-30) $= 88$
$(\alpha_1 - \alpha_2) = -64\frac{3}{4}$
} 1 meter from top of pole.

α_1 (80 μA) $= 22$
α_2 (30-30) $= 88$
$(\alpha_1 - \alpha_2) = -66$
} 2 meters down

Page Tightly Bound

5/19/28

Continued

$$\left.\begin{aligned} \alpha_1 &= 21 \\ \alpha_2 &= 88 \\ (\alpha_1 - \alpha_2) &= -67 \text{ TU.} \end{aligned}\right\} \text{3 meters down.}$$

$$\left.\begin{aligned} \alpha_1\ (80\,\mu A) &= 20.5 \\ \alpha_2\ (30\text{-}30\,\mu A) &\ \ 88 \\ (\alpha_1 - \alpha_2) &\ \ -67.5 \text{ TU} \end{aligned}\right\} \text{4 meters down.}$$

$$\left.\begin{aligned} \alpha_1\ (80\,\mu A) &= 20 \\ \alpha_2\ (30\text{-}30\,\mu A) &= 88 \\ (\alpha_1 - \alpha_2) &= -68 \end{aligned}\right\} \text{5 meters down}$$

$$\left.\begin{aligned} \alpha_1\ (80\,\mu A) &= 18\tfrac{3}{4} \\ \alpha_2\ (25\text{-}25\,\mu A) &= 88 \\ (\alpha_1 - \alpha_2) &= -69\tfrac{1}{4} \end{aligned}\right\} \text{6 meters down}$$

Cont. 3 8/16/28.

4 λ ◇ N_A : 1/6 t. 1 button pressed.

$$\left.\begin{array}{ll} \alpha_1\ (80\ \mu A) & : 22\tfrac{3}{4} \\ \alpha_2 (30\text{-}30\ \mu A) & : \underline{87.5} \\ (\alpha_1 - \alpha_2) & = -64\tfrac{3}{4} \end{array}\right\} \text{top of pole}$$

$$\left.\begin{array}{ll} \alpha_1\ (80\ \mu A) & : 21 \\ \alpha_2\ (30\text{-}30\ \mu A) & = \underline{87.5} \\ (\alpha_1 - \alpha_2) & = -66.5 \end{array}\right\} \text{1 meter down}$$

$$\left.\begin{array}{ll} \alpha_1\ (80\ \mu A) & : 19.5 \\ \alpha_2\ (30\text{-}30\ \mu A) & : \underline{87.5} \\ (\alpha_1 - \alpha_2) & = -68.0 \end{array}\right\} \text{2 meters down}$$

$$\left.\begin{array}{ll} \alpha_1\ (80\ \mu A) & : 18.0 \\ \alpha_2\ (30\text{-}30\ \mu A) & : \underline{87.5} \\ (\alpha_1 - \alpha_2) & : -69.5 \end{array}\right\} \text{3 meters down}$$

$$\left.\begin{array}{ll} \alpha_1\ (80\ \mu A) & : 16.5 \\ \alpha_2\ (30\text{-}30\ \mu A) & : \underline{87.5} \\ (\alpha_1 - \alpha_2) & : -71.0 \end{array}\right\} \text{4 meters down}$$

$$\left.\begin{array}{ll} \alpha_1\ (80\ \mu A) & : 13.5 \\ \alpha_2\ (30\text{-}30\ \mu A) & = \underline{87.5} \\ (\alpha_1 - \alpha_2) & : -74.0 \end{array}\right\} \text{5 meters down}$$

4 8/16/28

4 λ $\diamond$ cont.

$$\left.\begin{aligned} \alpha_1 (80\,\mu A) &= 17.0 \\ \alpha_2 (80\text{-}30\,\mu A) &= \underline{87.5} \\ (\alpha_1 - \alpha_2) &= -70.5 \end{aligned}\right\} \text{8 meter down}$$

λ

...t.Y ke 7.

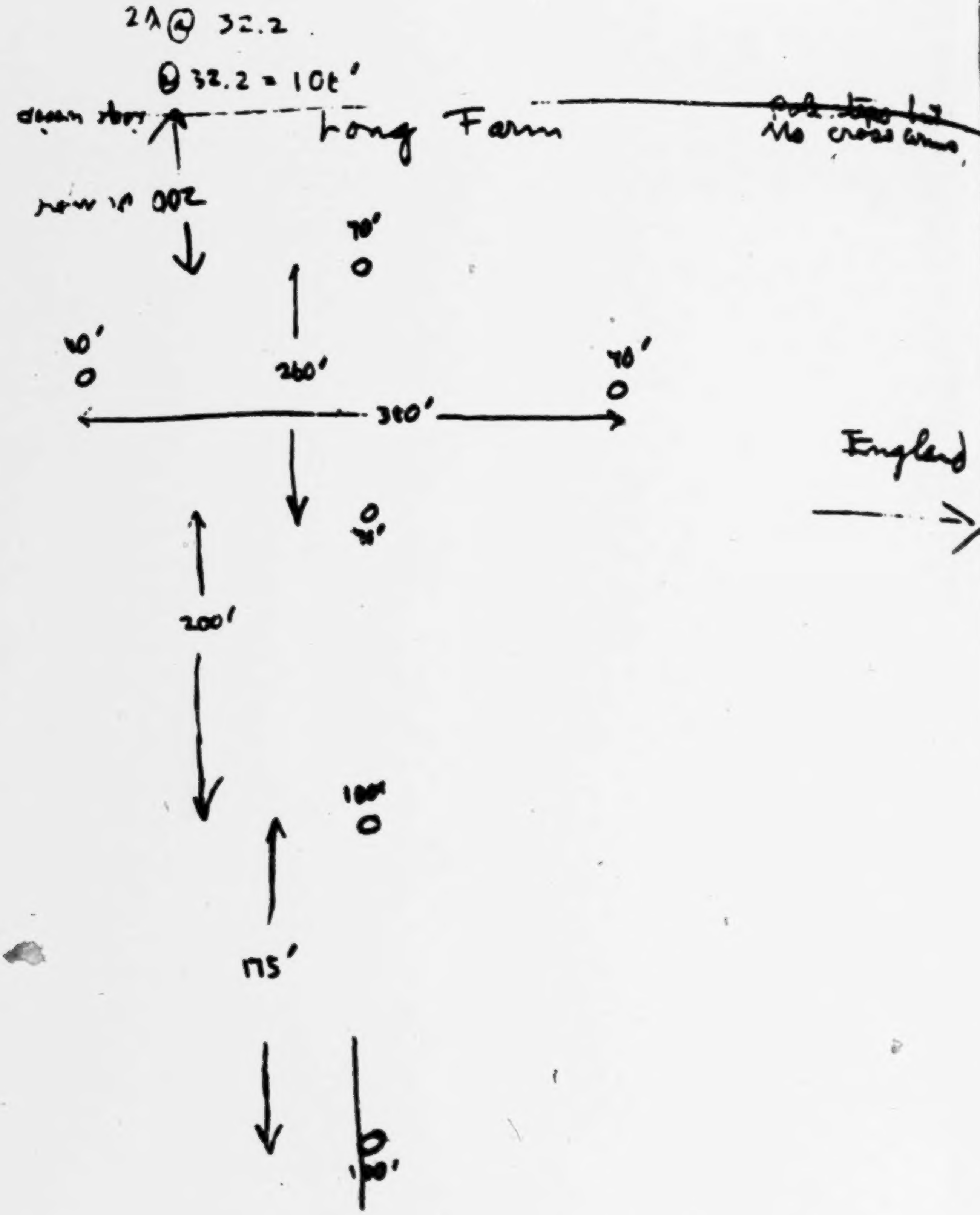
case 1 (vertical) filter sw. closed bottom pressed
1/Ct change - 80 μA - $\alpha_1 = 22$ α_2 for 29-29 = 87.5
$\alpha_1 - \alpha_2 = -65.5$ TU

λ tilt (toward oscillator) N_A = 1Ct/Ct 80 μa change
α_1 = 25.5 TU α_2 for 30-30 = 88.5 TU
$\alpha_1 - \alpha_2 = -63$ TU

λ tilt (away oscillator)
α_1 = 28.8 TU

2λ (away oscillator)

H from top of pole meters	α_1 (80 μa)
0	23 2

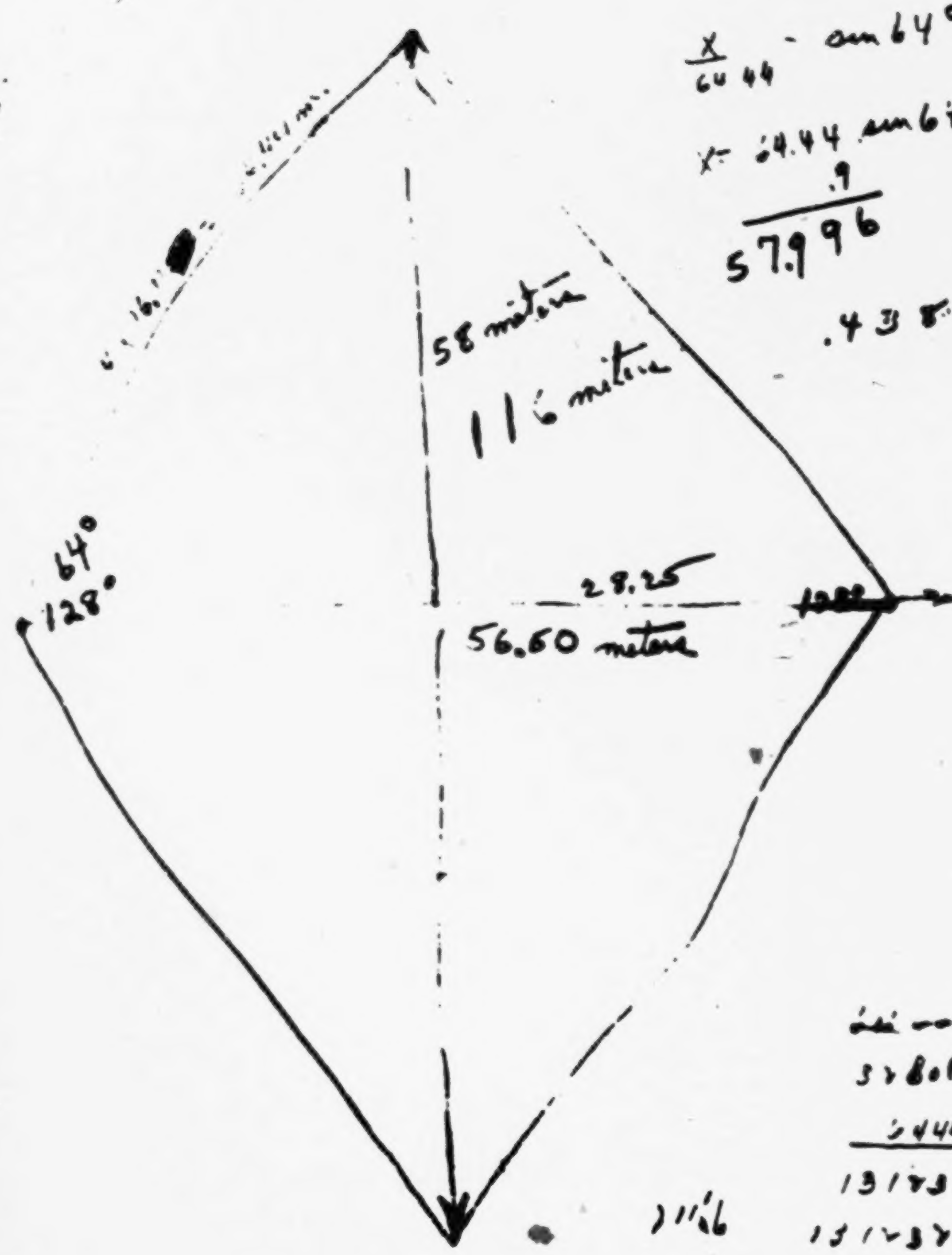

Long Farm
No cross arms
70'
70'
260'
70'
380'
England
200'
100'
175'

$\frac{x}{64.44} = \sin 64°$

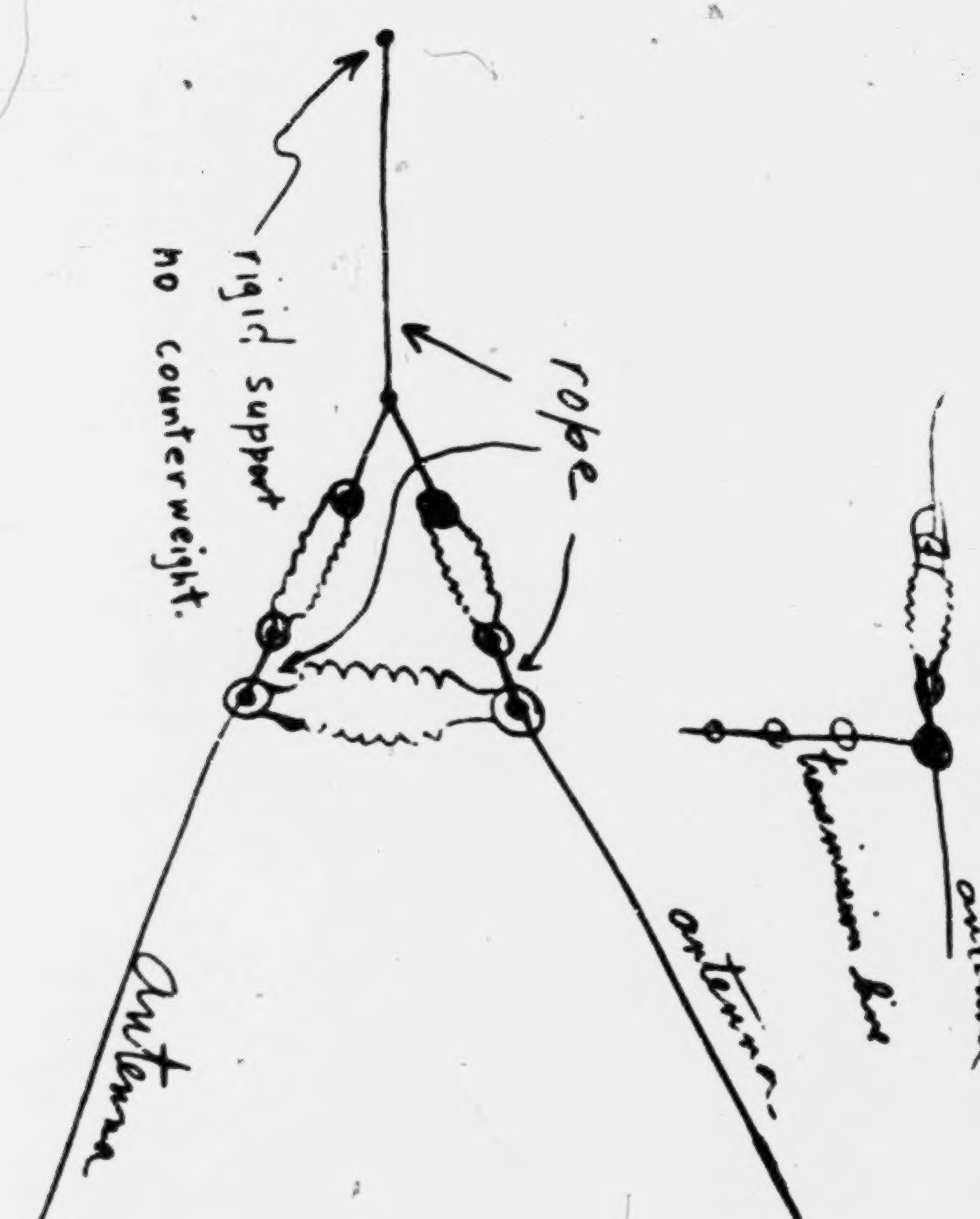
$x = 64.44 \sin 64°$

$\frac{\quad .9}{57.996}$

.438



32801
3444
131232
131232
131232
198481
11.6
11.414752


rope
rigid support
no counterweight.
Antenna
antenna
antenna
transmission line

Apr. 24, 1930

Horizontal Vee – front end open
oscillator at 16.11 metres – approx 825 ft. away

front → 19.0
back → 11.8
ratio 9.2

April 29. 1930

Ratio of horizontal to vertical pickup –
front end open, osc. approx 825 ft in front
at 16.1 metres, wax coupling, etc. → 30 db.

Frequency run.

B. setting		Osc. setting	wave m	M.C.	db	change db	
[illegible]	183.2	10					cannot tune antenna
177.2	179.3	15					" " "
172.9	179.8	20					" " "
168.1	170.1	25	14.88	20.2	44		full coupling not [illegible]
163.3	165.0	30			44.5		
160.0	161.0	35			45		
152.8	156.7	40			44		
148.0	152.1	45			42		
144.1	148.8	50			40.5		
139.5	143.1	55			42		
135.6	136.3	60			42.5		
129.8	133.9	65			40.5		
125.0	128.4	70			41		some interference from KKZ
120.0	125.0	75			39.5		coupling all in
115.2	120.3	80			40.5		
110.4	115.8	85			38		
105.6	111.2	90			37.5		
101.0	106.9	95			37		
96.0	102.4	100	29.65	10.45	36.5		

This page important to Patent Department.
First tests on Horizontal Rhombic Antenna.
E.B.

954

1165

Comparative Measurements on GBU. 5/1/30

set No. 14
2 buttons [illegible]

Time PM	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	
								[illegible]
2:45	78.0	82.5	25	17.5	59	65.0	+11.0	
:46			26	25	53	57.5	+4.5	
:47			24	17	55	65.5	+10.5	
:48			22	12.5	57	70	+13	
:49			20	6	59	76.5	+17.5	
:50			16	13	63	69.5	+6.5	
:51			18	8	61	79.5	+18.5	
52			18	8	61	79.5	+18.5	
53			14	7	65	75.5	+10.5	
54			15	7	64	75.5	+11.5	
55			15	10	64	72.5	+8.5	10
56			13	6	66	76.5	+10.5	9
57			18	5	61	77.5	+16.5	
58			25	12.5	54	70	+16.0	
59			27	17.5	52	65	+13.0	
3:00			35	18	44	62.5	+18.5	peak 40
3:01			38	32	41	[illegible]	+9.5	" 42
02			28	22	51	60.5	+9.5	
03			30	22	49	60.5	+11.5	
04			24	22	55	60.5	+5.5	
05			24	12	55	70.5	+15.5	
06			20	12	59	70.5	+11.5	
07			16	7.5	63	75.0	+12.0	
08			20	11	59	70.5	+11.5	
09			22	12	57	70.5	+13.5	
10			26	18	53	64.5	+11.5	
11			24	18	55	64.5	+9.5	
12			29	20	50	60.5	+10.5	
13			25	20	54	62.5	+8.5	
14			29	17	57	65.5	+13.5	
15			26	19	53	62.5	+11.5	
16			27	20	52	62.5	+10.5	
17			27	17	52	65.5	+13.5	
18			29	25	50	57.5	+7.5	
19			26	21	53	61.5	+8.5	
20			25	19	54	65.5	+11.5	
21			29	17	51	65.5	+14.5	
22			26	22	53	60.5	+7.5	
23			25	21	54	61.5	+7.5	
24			22	15	57	67.5	+10.5	
25	79.0	82.5	20	14	59	68.5	+9.5	44.0

April Work Report. OKB

During the month of April work was divided approximately as follows:-

Permanent equipment at Holmdel 10%
Supervision of pole setting by N.J. Bell Co. 20%
Horizontal "Vee" antenna 70%

The oscillograph and its associated equipment was completed during April. The batteries were wired to the new switch board, and the new battery charger installed. The monitoring and switching relay rack in our office was also completed.

The [redacted] new poles for the Holmdel site [redacted] were set [redacted] by the New Jersey Bell Telephone Company. Eight one hundred foot poles and ten seventy foot poles were erected. This work was completed on April tenth.

Work was then started on the erection and testing of a four wavelength horizontal vee antenna. This was erected on four seventy foot poles located on the same broadside line [redacted] as the other antennas on the Roberts Farm.

A new [redacted] set house was a

located and measuring set #14 is being used for measurements on this antenna. A number of circuits for connecting the transmission line to the set were tried and a suitably balanced one is now being used. In this circuit a tuned balancing transformer is used in a separate shielded box, and the output from this is tapped for proper impedance match into the antenna coil of the set. ratio hor to vert 30 db.

Studies of front end termination were then made. When a pure resistance is used approximately seven hundred ohms gives best front to back ratio (approx. 15 db.) and when a resistance of approximately nine hundred ohms and in ‖ with an inductance is used front-back ratios of more than 50 can be obtained.

A frequency run ~~with~~ was made with the front end open, [illegible]

Readings were then taken of ~~the~~ average level of GBV in db. below one volt each minute over a forty minute period, and then compared with the recorded values

Page Tightly Bound

on the half wave vertical antenna. This shows that the horizontal vee antenna gave an approx improvement [redacted] of about eleven db. above the half wave vertical during this observed period. More careful observations of the improvement can be made when the recorder is in operation on the horizontal vee ...

The month of May was spent on work in connection with the development of the horizontal wire antenna. About seventy-five percent was spent in work on the antenna and its termination, and twenty five percent on adapting set #14 for continuous recording.

Further work was done on the termination of the antenna for good front to back ratio. New carbon resistors of a larger and more substantial type than pencil leads were obtained and are being used. Frequency runs have been taken for terminations consisting of a pure resistance alone and a resistance and reactance ~~together~~. Good front to back ratio can be obtained over a comparatively large frequency range.

Work has been ~~carried on~~ done on the equipment in the termination box between the lead in and the pipe line. An endeavor has been made to get a flat frequency characteristic over a large range without retuning the condensers in this equipment. To do this tight coupling of the two coils has been used. A substantially flat characteristic

is been obtained from thirteen to nineteen megacycles.

Most time was spent with Mr. [illegible] in obtaining attenuation curves along the ground for both vertically and horizontally polarized waves. The results of this work will be reported by him.

A test of the horizontal antenna shows that the ~~peak~~ response of ~~to~~ vertically polarized waves coming in from the ninety degree position is no greater than ~~[illegible]~~ the response to the same type of radiation in front of the antenna.

In cooperation with Mr. Lowry work is progressing in remodeling sets #14 and 17 for continuous recording work. The new attenuator panels are now completed and the recorders have arrived.

DEFENDANT'S EXHIBIT UU

1927523

NUMBER (Series of 1925)

33-177

1928
1929

PATENT NO.

DIV. 51

DATED SEP 1 0 1933

(EX'R'S BOOK) 133 / / 3

Name NILS E. LINDENBLAD

Assor to Radio Corporation of America, a corp of Delaware

of PORT JEFFERSON, LONG ISLAND

State of NEW YORK

Invention

ANTENNAS FOR RADIO COMMUNICATION

	ORIGINAL	RENEWED
APPLICATION FILED COMPLETE	DEC 24, 1928	
Petition, Specification, Oath, First Fee $20, 1 sheets Drawings.	DEC 24, 1928	
Examined and passed for Issue	Feb. 21, 1933	Reexam'd and passed for Issue ....., 192
	Ex. Div. 51	Ex. Div.
Notice of Allowance	Feb. 21, 1933 By Commissioner	Notice of Allowance ....., 192 By Commissioner
Final Fee	Aug 23, 1933	Final Fee ....., 192

Attorney IRA J. ADAMS C/O RADIO CORP OF AMERICA ~~233 BROADWAY~~ NEW YORK N

Associate Attorney H. G. Grover, 570 Lexington Ave, 30 Rockefeller Plaza

No. of Claims Allowed 23 Print Claim 3 in O. G. Class 250-33

Title as Allowed Antennas for Radio Communication

1929

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2. Assignment	Apr. 26, 1929	27.	
3. Rej.	Apr. 25, 1929	28.	
4. Amendment A } [illegible]	Jan. 30, 1930	29.	
5. Rej.	Nov. 5, 1930	30.	
6. Aff. of Add.	Apr. 23, 1931	31.	
7. Amdt. B	May 5, 1931	32.	
8. Letter	Dec. 14, 1931	33.	
9. Amendt. C	Mar. 2, 1932	34.	
10. Rej.	March 9, 1932	35.	
11. Amendt. D	Mar. 8, 1932	36.	
12. Amendt. E	Aug 5, 1932	37.	
13. Rej.	Dec. 9, 1932	38.	
14. Amendt. F	Jan. 3, 1933	39.	
15. Amdt. [illegible] (78)	June 16, 1933	40.	
16. [illegible]	June 21, 1933	41.	
17. [illegible]	AUG 4 1933	42.	
18. LETTER (cap)	AUG 17 1933	43.	
19. AMENDMENT [illegible]	AUG 17 1933	44.	
20. Notice of [illegible]	Aug. 18, 1933	45.	
21. [illegible]	Sept. 6, 1933	46.	
22. [illegible]	April 27, 1934	47.	
23. Title Report	June 2, 1934	48.	
24. [illegible]		49.	
25. [illegible]	AUG 9 1934	50.	

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$ 20- RECD
ck

DEC 24 28
C.C.U.S.PAT.OFFICE

328147

117

522

PETITION

JAN 4 - 1929

TO THE HONORABLE COMMISSIONER OF PATENTS:

Your petitioner, NILS E. LINDENBLAD

a citizen of the United States, residing at Port Jefferson, Long Island,

in the County of Suffolk State of New York

whose Post Office address is Port Jefferson, Long Island, New York.

prays that Letters Patent may be granted him for the improvement in

ANTENNAS FOR RADIO COMMUNICATION

set forth in the accompanying specification.

And he further prays that you will recognize Wm J. Adams, care of Radio Corporation of America, ~~[illegible]~~ 233 Broadway, New York, as his attorney, with full power of substitution and revocation, to prosecute this application, to make alterations and amendments therein, to receive the patent, and to transact all business in the Patent Office connected therewith.

S P E C I F I C A T I O N

TO ALL WHOM IT MAY CONCERN:

BE IT KNOWN THAT I, NILS E. LINDENBLAD, a citizen of the United States and resident of Port Jefferson, Long Island, New York, have invented certain new and useful improvements in

ANTENNAS FOR RADIO COMMUNICATION

of which the following is a specification accompanied by drawings:

9

This invention relates to antennas for radio communication.

Short wave antennas suffer from the disadvantage of having to be rather critically tuned to the working frequency, and from the further disadvantage of necessitating the use of some kind of an impedance matching device between the antenna and the transmission line connecting the antenna with the radio equipment. It is an object of my invention to provide an exceedingly simple form of short wave antenna which will operate over a considerable range of frequency, and a further object of my invention is to provide an antenna with which a transmission line may be coupled without the use of intermediate impedance matching devices.

My antenna consists simply of a pair of conductors which at one end are spaced at the spacing of the transmission line, and are coupled thereto, and which gradually diverge to a much wider spacing at their other ends. In effect, therefore, the antenna consists merely of a gradually diverging extension of the conductors of the transmission line, and, in one aspect, the invention resides in the discovery that radiation may be obtained from a transmission line by gradually increasing the spacing between the wires of the line.

The desired radiation takes place in the direction of the axis of the pair of conductors, and is caused by the expansion of the current or the travelling wave of energy in the conductors. Reflection will cause a standing wave, instead of a travelling wave, and result in radiation sideways from the antenna. Despite this, the radiation in the direction of the antenna is still considerably greater than that obtainable from a simple doublet. However, as a refinement the harmonic radiation may be lessened by reducing the standing waves, and to so do is a further object of my invention. It is not feasible, in the case of a transmitting antenna, to avoid standing waves by closing the end of the antenna with a surge resistance, because of the excessive losses which would take place therein.

To lessen the standing wave I reduce the reflected energy by radiating as much of the energy fed to the antenna as possible To merely increase the dimensions of the antenna is not practicable, for to increase the length without increasing the spacing, that is, to decrease the angle of divergence, does not increase the radiation, and on the other hand, to keep the same angle of divergence necessitates so wide a spacing as to make the antenna structurally inconvenient. To overcome this I employ a plurality of antennas or pairs of diverging conductors, arranged end to end, so as to radiate cumulatively.

I have also found that a pair of converging conductors, like a pair of diverging conductors will radiate energy, but this radiation is in opposite phase. The antenna may therefore comprise a plurality of pairs of conductors which successively diverge and converge, with means coupling the antennas which reverse the phase of the energy fed thereto.

While the terminology employed in the foregoing description may apply more particularly to a transmitting antenna the structure set forth is equally useful as a receiving antenna.

The invention is further described in the following specification, which is accompanied by a drawing in which

Figure 1 represents one form of my invention;

Figure 2 is a modification employing straight conductors;

Figure 3 shows the use of a plurality of diverging and converging antennas;

Figure 4 is a section of figure 3 taken on the line 4-4; and

Figure 5 is a modification of figure 3 showing an alternative form of phase reversing coupling means between the successive antennas.

Referring to figure 1 it will be seen that the antenna consists of a pair of conductors 2, 4, which are connected to a transmission line 6 at points 8 and 10, which are spaced at the spacing of the transmission line. From the points 8 and 10 the conductors 2 and 4 gradually diverge to a much wider spacing at the ends 12 and 14. The extension of the conductors may be curved, as shown, and one form which is quite successful in operation is an expansion according to an exponential law.

However, in actual practice I find that the refinement of an exponential curve is not essential, and that the conductors 2 and 4 may be straight conductors strung between the points 8 and 12, and the points 10 and 14, under direct tension, and without the use of intermediate shaping or guy wires, and such an arrangement has been indicated in figure 2.

No impedance matching device is necessary with this antenna, so that in actual practice the antenna is exceedingly simple to erect, it being necessary merely to provide a pair of supporting points 12 and 14 at a desired distance from the termination of the transmission line, and then to continue the conductors of the transmission line directly to the spaced points 12 and 14.

Whatever amount of energy has not been radiated when the travelling wave reaches the end of the antenna is reflected, and thus causes a partial standing wave, which will extend back along the transmission line 6. If the transmission line is short, this may be neglected, but if the transmission line is long, and the antenna is relatively small, so that only a small portion of the energy is radiated, it may prove desirable to employ an impedance matching device between the transmission line and the antenna, as is indicated by the impedance matching unit 16, shown in figure 2.

a4/1

If, instead, the antenna is made to radiate more energy, the standing wave will incidentally be reduced, and the impedance matching device may be dispensed with. To merely make the antenna much longer, while keeping the same spacing at its open end, does not help, because such a procedure merely slows up the rate of spread of the energy, and does not increase the quantity of energy radiated. On the other hand it ordinarily is not structurally possible to make the antenna considerably longer while maintaining the same angle of divergence of the conductors, owing to the great spacing which would be needed at the open end of the antenna. The same result may be accomplished without these disadvantages by using a plurality of antenna sections arranged end to end. Since a converging antenna is similar in operation to a diverging antenna, except for a reversal in phase, it becomes especially convenient to use a plurality of antenna sections which are successively diverging and converging, and such antennas have been indicated in figures 3 and 5.

Referring to figure 3 it will be seen that a transmitter 20 is coupled to a diverging antenna 22 by a transmission line 4. The diverging antenna 22 is followed by a converging antenna 24, which is coupled to the diverging antenna 22 by a pair of conductors 26 and 28. The spacing between these conductors is kept constant, so that practically no radiation takes place therefrom, but at the same time the conductors are electrically crossed in order to reverse the phase of the energy being fed from antenna 22 to antenna 24. For this purpose each of the conductors is supported, at least approximately, in the form of a helix, a feature which is more clearly indicated in the section taken on the line 4-4, and constituting figure 4. The pitch of the helices should be sufficiently great that the physical distance in space between the antennas 22 and 24 is substantially equal to the distance along the conductors 26 and 28, so that the phase displacement of the wave travelling in space will coincide with that of the energy wave travelling on the conductors 26 and 28. The converging antenna 24 is followed by a diverging antenna 30, and the adjacent ends of the antennas 24 and 30 are coupled by phase reversing coupling conductors 32 and 34.

A modification of the arrangement shown in figure 3 is indicated in figure 5, in which a transmitter 20 is coupled by a transmission line 24 to a diverging antenna 22, followed by a converging antenna 24, which in turn is followed by a diverging antenna 30, such as in figure 3. However, in this case the antennas 22 and 24 are coupled by conductors 40 and 42, which are a half wave in length, in order to reverse the phase of the energy flowing therethrough, and which are bent back upon themselves so as to be substantially nonradiating. The connection between the antennas 24 and 30 is made simply by crossing the conductors, as shown, the conductors being separated slightly at the crossing point by an insulator in order to prevent a short circuit between the conductors. In the arrangements shown in figures 3 and 5 any desired number of antenna sections may be employed.

The plane of polarization of the radiated energy coincides with the plane of the conductors, so that if the conductors are positioned in a horizontal plane the energy is radiated with horizontal polarization, and if the conductors are positioned in a vertical plane the energy is radiated with vertical polarization.

With the conductors in a horizontal plane a standing wave tends to cause side radiation. By locating the conductors in a vertical plane the directivity in azimuth may be maintained regardless of the presence of standing waves, but even in such case it is desirable to prevent waste of the energy radiated thereby, and it is therefore desirable to make the length of the conductors or the number of antenna sections sufficiently great, in accordance with the foregoing instruction, to reduce the standing wave.

Insert H

It will be understood by those skilled in the art that if improved directivity is desired a plurality of these antennas may be employed abreast or in broadside, that is to say, collaterally spaced apart in parallel formation along a line at right angles to the desired direction of communication.

Since the preferred radiation is from the travelling wave, and is due to the expansion of the lines of force between the current charges travelling along the conductors, the divergence should preferably be fairly gradual, and the spacing at the open end, while variable over a great range, should be in the neighborhood of a fifth of the length, and the length of each antenna section should be of the order of magnitude of five to ten waves long.

The antenna is equally suitable both for transmission and reception, the energy in the latter case being collected and converged into the transmission line without the necessity of an impedance matching device.

9 ac

I CLAIM:

Pat a 1. The method of directionally radiating or collecting high frequency electrical energy which includes directing the energy of opposite polarity in a plurality of gradually diverging paths diverging and extending longitudinally in the desired direction of radiant action.

Add B'cl.2

elr

Sub B' 2. ~~The method of radiating or collecting high frequency electrical energy which includes directing the energy of opposite polarity in a plurality of gradually converging paths diverging and extending longitudinally in the desired direction of radiant action.~~

band limited

a 3. The method of radiating or collecting high frequency electrical energy which includes directing the energy of opposite polarity successively in a plurality of gradually diverging and converging paths and phase reversing the energy as it is directed from one path...

Add C'cl.4

B 4. ~~The method of radiating or collecting high frequency electrical energy which includes directing the energy in a pair of gradually diverging paths, and preventing reflection of the energy travelling in these paths.~~

5. ~~The method of radiating or collecting high frequency electrical energy which includes directing the energy successively in a pair of gradually diverging and converging paths until reflected energy is reduced to a desired minimum.~~

Sub C'

B 6. A unidirectional antenna comprising a gradually diverging pair of conductors diverging and extending longitudinally only in a desired direction of radiant action excited in phase opposition.

B 7. A unidirectional antenna comprising a gradually diverging pair of conductors diverging and extending longitudinally only in the direction of desired communication excited in phase opposition.

B 8. A unidirectional antenna comprising a gradually converging pair of conductors excited in phase opposition, converging and extending longitudinally only in the direction of desired communication.

unidirectional … in phase opposition longitudinally

9. An antenna comprising a pair of conductors extending in the direction of desired communication, the effective portions of which gradually diverge and converge successively.

unidirectional longitudinally

10. A transmitting antenna comprising a pair of conductors extending in the direction of desired transmission, the radiating portions of which gradually diverge and converge successively in the direction of desired transmission.

two-conductor … in phase opposition extending longitudinally in the direction of transmission

11. In combination, a transmission line, and an antenna connected thereto comprising gradually diverging extension of the conductors of the transmission line at their remote open ends.

extending longitudinally in the direction of desired radiant action

12. In combination, a two-conductor transmission line, and an antenna spaced … in phase opposition comprising an open ended pair of conductors which at one end are spaced at the spacing of the transmission line and are coupled thereto, and which gradually diverge to a much wider spacing at their open ends.

extending longitudinally in the direction of desired radiant action

13. In combination, a transmission line, and an antenna connected thereto comprising a pair of open ended conductors of the order of magnitude of a number of wave lengths long which are widely spaced at the ends remote from the transmission line, and energized with energy of opposite polarity and spaced at the spacing of the transmission line at their junction therewith.

unidirectional longitudinally

16 An antenna comprising a plurality of pairs of gradually diverging conductors extending in the direction of desired transmission and energized in phase opposition

~~16~~ 20. In combination, a transmission line, an antenna connected thereto comprising a pair of conductors a number of wave lengths long which are spaced at the spacing of the transmission line at their junction therewith, and which gradually diverge to a much wider spacing at their remote ends, a second antenna comprising a pair of conductors a number of wave lengths long arranged in extension of the first antenna, and widely spaced at their near ends and closely spaced at their remote ends, another diverging antenna arranged in extension of the converging antenna, and phase reversing means for coupling said antennas together.

Insert C-2 ~~do~~ 13-15

Insert E ~~do~~ 14-29 ~~1~~

add G'

Opened

Nils E. Lindenblad

BSF:AU

AFFIDAVIT

STATE OF ....NEW YORK.........
COUNTY OF ....SUFFOLK......... } SS.:

...........NILS E. LINDENBLAD........... the above named petitioner, being duly sworn, deposes and says that he is a citizen of the United States and resident of Port Jefferson, L.I. in the County of Suffolk, State of New York.

and that he verily believes himself to be the original, first, and sole inventor of the improvements in

..........ANTENNAS FOR RADIO COMMUNICATION..........

....

described and claimed in the annexed specifications; that he does not know and does not believe that the same were ever known or used before his invention or discovery thereof; or patented or described in any printed publication in any country before his invention or discovery thereof or more than two years prior to this application; or patented in any country foreign to the United States on an application filed by himself or his legal representatives or assigns more than twelve months prior to this application; or in public use or on sale in the United States for more than two years prior to this application; and that no application for patent on said improvements has been filed by him or his representatives or assigns in any country foreign to the United States.

....

....

....

Nils E. Lindenblad

Sworn to and subscribed before me this Seventeenth (17th)

day of December, 1938.

W A Graff
Notary Public.

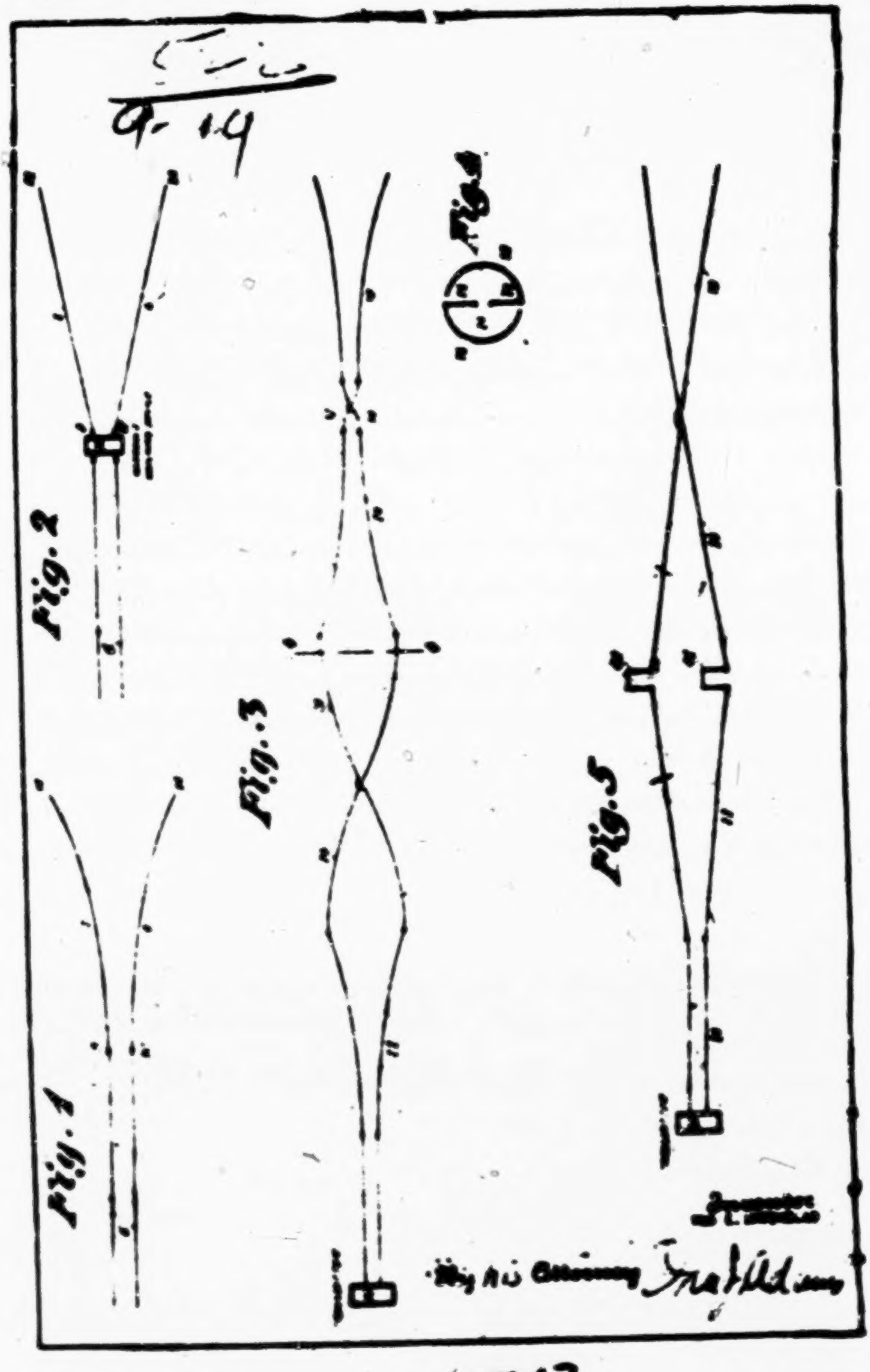
Fig. 1
Fig. 2
Fig. 3
Fig. 4
Fig. 5

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By

#2

MAIL DIVISION
APR 26 29
U.S. PATENT OFFICE

IN THE UNITED STATES PATENT OFFICE

- -

APPLICATION OF N. E. LINDENBLAD :

FOR ANTENNAS FOR RADIO COMMUNICATION :

SERIAL NO. 228,147 FILED: Dec. 24, 1928 :

DIVISION 51 ROOM NO. 240 Ax. :

LAST OFFICE ACTION: :

- -

New York, N.Y., March 7, 1929.

COMMISSIONER OF PATENTS,

WASHINGTON, D. C.

Sir:

APPOINTMENT OF ASSOCIATE ATTORNEY.

I hereby appoint, H. G. GROVER, (Register Number 3988), whose Post Office address is C/o Radio Corporation of America, 233 Broadway, New York, New York, as associate attorney to prosecute the above entitled application, to make alterations and amendments therein, to receive the patent and to transact all business in the Patent Office connected therewith, and I further direct that all correspondence concerning the aforesaid application be mailed to the said associate attorney appointed hereby.

Lloyd Adams
Attorney of Record.

Div. 51 Room 240-Annex Paper No. 3

DEPARTMENT OF COMMERCE
UNITED STATES PATENT OFFICE
WASHINGTON September 25, 1929.

RPM:MCG

SEP 25 1929

Please find below a communication from the EXAMINER in charge of this application.

Thomas E. Robertson
Commissioner of Patents.

Applicant: N. E. Lindenblad

H. G. Grover,
C/o Radio Corp. of America,
233 Broadway,
New York, N. Y.

Ser. No. 328,147
Filed Dec. 24, 1928
For Antennae for Radio Communication.

This application has been examined.

Record is made of:

Artom	794,334	July 11, 1905	250-11
Garcia	795,762	July 25, 1905	250-11
Athearn	918,256	Apr. 13, 1909	250-33
Fessenden	1,147,010	Jul. 20, 1915	250-33

"The Wireless Age", September, 1921, pages 36 and 37, published by The Wireless Press, Inc., 250-33.

In the drawing, the phase reverser should be indicated as such so as to illustrate the combination.

Claims 1, 6, 7, 12, 13 and 14 are rejected on any one of the references, Wireless Age, Artom or Garcia.

Claims 2 and 8 are rejected on Fessenden who shows converging antenna.

Claim 3 is rejected on Athearn who shows antenna arranged with the conductors in successively diverging and converging paths.

Claims 4 and 5 are rejected like claim 3. The only distinction over the reference is in functional limitations. Furthermore, claim 4 is inaccurate in claiming preventing reflection of energy. Apparently all that applicant does is reduce the reflection of energy.

Claims 9, 10 and 11 are rejected on Athearn like claim 3.

Claim 15 appears to be allowable.

R.M.

O. O. Buckner
Examiner

4 a

IN THE UNITED STATES PATENT OFFICE

JAN 30 30

APPLICATION OF NILS E. LINDENBLAD :
FOR ANTENNAE FOR RADIO COMMUNICATION :
SERIAL NO. 328147 FILED DEC. 24, 1928 :
DIVISION 51 ROOM 240-ANNEX :
LAST OFFICE ACTION: SEPTEMBER 25, 1929 :

New York, N. Y. January 29, 1930.

COMMISSIONER OF PATENTS,

WASHINGTON, D. C.

SIR:

In response to the Office Action of September 25, 1929, kindly amend as follows:

Claim 1, line 1, before "radiating" insert directively.

Line 2, cancel "the".

Line 2, after "energy" insert of opposite polarity.

Last line, before the period insert diverging and extending longitudinally in the desired direction of radiant action.

Claim 2, line 2, cancel "the".

Line 2, after "energy" insert of opposite polarity.

Line 3, before the period insert diverging and extending longitudinally in the desired direction of radiant action.

Claim 3, line 2, cancel "the".

Line 2, after "energy" insert of opposite polarity.

Last line, before the period, insert and phase reversing the energy as it is directed from one path into another.

Claim 6, line 2, before the period insert diverging and extending longitudinally only in a desired direction of radiant action.

Claim 7, line 2, after "conductors" insert diverging and.

Line 2, after "extending" insert longitudinally only.

Claim 8, line 2, after "conductors" insert excited in phase opposition, converging and.

Line 2, after "extending" insert longitudinally only.

Claim 9, line 1, after "extending" insert longitudinally.

Claim 10, line 2, after "extending" insert longitudinally.

Last line, before the period, insert in the direction of desired transmission.

Claim 11, line 2, after "thereto" insert extending longitudinally in the direction of transmission.

Claim 12, line 1, after "antenna" insert extending longitudinally in the direction of desired radiant action.

Claim 13, line 1, after "antenna" insert extending longitudinally in the direction of desired radiant action.

Line 4, before the comma, and after "line" insert and energized with energy of opposite polarity.

Claim 14, line 2, after "extending" insert longitudinally.

Last line, before the period, insert and energized in phase opposition.

REMARKS:

The Official Draftsman has been requested to amend the drawing as suggested.

Favorable reconsideration of claims 1, 6, 7, 12, 13 and 14 over the art of record is thought to be in order and is, therefore, respectfully requested.

Turning to claim 1, no one of the references of record discloses the transmission of energy of opposite polarity in a

plurality of diverging paths diverging and extending longitudinally in the desired direction of radiant action. In addition, no one of the references teaches phase reversal of energy as it travels from the converging path to the diverging path or vice versa. And, similar to claim 1, no one of the references teaches as called for by claims 13 and 14 conductors diverging and extending longitudinally in the direction of desired transmission, which conductors are energized in phase opposition.

Artom discloses antennae of two sections which extend longitudinally downwardly and not in the direction of desired transmission. Similarly, Athearn fails to show conductors extending longitudinally or diverging in the desired direction of radiant action. Fessenden fails to disclose diverging or converging conductors excited in phase opposition. The latter failure is also present in the Garcia patent and in the Wireless Age article cited against this case.

Turning to claims 6 and 7 the Examiner's attention is respectfully directed to the feature therein to the effect that the conductors diverge and extend longitudinally only in a single direction, that being the direction of desired radiant action. The Wireless Age discloses at best, a non-directional antenna; for, it is stated therein that most of the radiation occurs from the vertical connection to the antenna which, as is well known in the art, radiates uniformly about its axis. Garcia discloses conductors which extend in more than the desired direction of transmission as does also Fessenden. As the Athearn antenna extends vertically it, of course, does not extend in the desired direction of radiant action. Artom, of course, does not extend longitudinally in the direction of radiant action but extends longitudinally downwardly.

As Athearn fails to disclose phase reversal of energy as it travels from a diverging path to a converging path it, of course, is inapplicable in the rejection of claim 5 which now calls for such phase reversal.

The prevention of reflection of energy in antennae of applicant's type is a new and useful teaching in the art and, therefore, is entitled indubitably to patent protection. Applicant discloses in his specification that reflection is detrimental to proper radiant action and that it may be effectually prevented in two ways; first, by terminating his antenna with a suitable resistance which, however, applicant points out, is objectionable because of the waste of energy; and secondly, and more important, applicant teaches that by making his antenna sufficiently long reflection is prevented by virtue of the fact that all of the energy is radiated. However, applicant shows that to make an antenna of one section sufficiently large to radiate all of the energy would not be practically feasible. He then teaches the art that by making it a plurality of sections successively diverging and converging, the antenna may be retained within workable physical limits without the presence of detrimental reflection phenomena. None of the art teaches the problem and still less does any of it solve the problem. Accordingly, claims 4 and 5 which state reflection prevention as a positive step are unequivocably patentable over the art of record and should upon the next Office Action be allowed.

Remarks similar to those given hereinbefore apply with equal cogency to claims 9, 10 and 11 which call for diverging and converging sections for an antenna extending longitudinally in the desired direction of radiant action. Moreover these claims call for the gradual divergence or convergence of the sections which, it is submitted, is not taught by Athearn, the reference relied upon in rejecting these claims. Athearn shows sharp divergence from his transmission lines 8-8 which, in short wave work for which applicant's antenna system is especially adapted, would prove highly detrimental and prevent proper action.

For the foregoing reasons allowance of the case in its present form is thought to be in order and is, therefore, respectfully requested.

Respectfully submitted,

NILS E. LINDENBLAD

BY H. G. Grover
Attorney

HT:AV

4

Radio

MAIL DIVISION JAN 30 30 PATENT OFFICE

IN THE UNITED STATES PATENT OFFICE

APPLICATION OF NILS E. LINDENBLAD	:
FOR ANTENNAE FOR RADIO COMMUNICATION	:
SERIAL NO. 388,147 FILED DEC. 24, 1928	:
DIVISION 81 ROOM 840-ANNEX	:
LAST OFFICE ACTION: SEPTEMBER 25, 1929	:

C print

New York, N. Y. January 28, 1930.

COMMISSIONER OF PATENTS,
WASHINGTON, D. C.

ACCOUNT JAN 31 1930 DIV 81 FILED

ATT: OFFICIAL DRAFTSMAN

SIR:

The Official Draftsman is requested to add the legend "phase reverser" on the drawing as it appears in ink on the accompanying print. It is requested that, when the additions have been made, the photostat be returned to applicant; and, that the cost of making the additions be charged to the account of Radio Corporation of America.

Respectfully submitted,

NILS E. LINDENBLAD

BY ______ Attorney

Approved 2/15/30 P.M.

RECEIVED IN DIV. C FEB 11 1930

HT:AU

CORRECTION ORDERED FEB 19 1930

50 ¢

CORRECTED FEB 24 1930

ACCOUNT CHARGE FINANCIAL ... DRAFTING DIV.

51 240-Annex

Paper No. 5

DEPARTMENT OF COMMERCE
UNITED STATES PATENT OFFICE

RFL:LCG WASHINGTON November 8, 1930

Thomas E. Robertson

NOV 8

Applicant H.E.Lindenblad

H. G. Grover,
C/o Radio Corp. of America,
233 Broadway,
New York, N. Y

Ser. No. 328,147
Filed Dec. 24, 1928
For Antennae for Radio Communication

Responsive to applicant's communications of January 30, 1930.

Additional record is made of:

Espenschied	1,353,735	Sept. 21, 1920	250-33
Stanley	1,738,489	Dec. 3, 1929	250-33
British Patent	223,742 (1 sht.)	Oct. 30, 1924	250-33

The operation of applicant's device to give directional transmission is questioned. It is not seen how two lines as shown by applicant will give the desired effect. Applicant should give a satisfactory explanation, or submit proper proof of the operativeness of the device to give the directional effects ascribed to it.

The claims are accordingly all rejected as being drawn to a device inoperative to perform the functions desired.

Claims 2 and 8 as amended are further rejected as misdescriptive since they recite "gradually converging paths diverging". Apparently the paths should converge instead of diverge.

Claim 4 is further rejected as unpatentable over athearn, since it is not new as shown by Espenschied to prevent reflection in an antenna.

Claim 4 is further rejected as misdescriptive since it appears that applicant merely reduces the reflection of

energy and does not prevent reflection.

Claim 5 is rejected as unpatentable over the British patent, supra, since no method different from that used in the British patent is included in the claim. Since the wires of this reference successively converge and diverge, it follows that energy directed along this antenna follows a converging and diverging path. Applicant's method merely adds the statement about reflection being reduced by this process but gives no additional steps over those made in using the British antenna.

Claims 6, 7 and 9 are rejected as unpatentable over Garcia, of record, or Stanley, supra. Both these references show an antenna composed of conductors extending in the direction of transmission. The limitation, "diverging and extending only in the direction of desired communication" is indefinite and does not point out the invention. The direction of "desired communication" may be in all directions.

Claims 10 and 11 are rejected as unpatentable over the British patent, supra, since the limitation as to the direction of the antenna with respect to the transmission line is considered immaterial.

Claims 1, 3, 12, 13, 14 and 15 appear to distinguish over the references and may be considered allowable upon satisfactory showing of the operativeness of the device.

R M

A. D. Bannon
Examiner

#6

UNITED STATES PATENT OFFICE

APPLICATION OF: NILS E. LINDENBLAD

FOR: ANTENNAS FOR RADIO COMMUNICATION

SERIAL NO. 328,147 FILED: Dec. 24, 1928

DIVISION: 51 ROOM: 240-ANNEX

April 22, 1931.
New York, N. Y.

The Commissioner of Patents

Washington. D. C.

Sir:

On and after April 24, 1931, please address all communications intended for the attorney of record of the above entitled case to

Harry G. Grover
c/o Radio Corporation of America
570 Lexington Avenue
New York City, N. Y.

Respectfully,

NILS E. LINDENBLAD

by H. G. Grover
Attorney

986

119

PAPER NO. 7
AMENDMENT

MAIL DIVISION
MAY 6 31
U.S. PATENT OFFICE

IN THE UNITED STATES PATENT OFFICE

APPLICATION OF: NILS E. LINDENBLAD
FOR: ANTENNAS FOR RADIO COMMUNICATION
SERIAL NO: 3??,147 FILED: DEC. 24, 1928
DIVISION: 51 ROOM: 24?-ANNEX
LAST OFFICE ACTION: NOVEMBER 8, 1930

New York, N. Y. April 28, 1931.

MAY 6 - 1931

COMMISSIONER OF PATENTS,

WASHINGTON, D. C.

SIR:

In response to the Office Action of November 8, 1930, kindly amend this case as follows:

Cancel claim 3 and rewrite it as follows:

~~16.~~ 20 The method of unidirectionally radiating or collecting high frequency electrical energy which includes directing energy of opposite polarity in a plurality of gradually converging paths converging and extending longitudinally in the desired direction of radiant action.

Cl. 3 foll

23'

Cancel claim 4.

Cancel claim 5.

Claims 6, 7, 8 and 9, change "An" to a unidirectional.

Claim 6, line 2, after "conductors" insert excited in phase opposition.

Claim 7, line 2, after "conductors" insert excited in phase opposition.

Claim 9, line 1, after "conductors" insert excited in phase opposition.

Claim 10, line 1, before "transmitting" insert unidirectional

Line 2, after "conductors" insert excited in phase opposition.

"N.

Claim 11, line 1, before "transmission" insert two conductor.

Line 1, after "line" and before the comma insert excited in phase opposition.

Claim 12, line 1, before "transmission" insert two conductor.

Line 1, after "line" and before the comma insert excited in phase opposition.

Claim 14, line 1, change "An" to a unidirectional.

REMARKS:

Applicant is surprised at the Examiner's rejection of this case on the ground of inoperatability. As proof of the operativeness of his present invention applicant submits herewith radiation curves derived from an antenna such as described in his present patent application. If the Examiner desires further proof of the operativeness of applicant's present invention, a mathematical treatment of the operation of his improved directional antenna arrangement will be given. Consequently, it seems that the rejection of the claims as being drawn to an inoperative device must be withdrawn.

Claim 2 has been rewritten so as to avoid the formal objection thereto. Applicant, however, fails to find any objection such as pointed out by the Examiner in connection with claim 8 and accordingly this claim has been allowed to stand as originally presented and amended heretofore.

Inasmuch as applicant feels that the subject matter of claims 4 and 5 is amply covered by the other claims retained in applicant's application, claims 4 and 5 have been cancelled. This cancellation, therefore, is not to be considered at all prejudicial to applicant who does not feel that the art of record teaches the subject matter of these cancelled claims.

It is respectfully submitted that claims 6 to 9 inclusive patentably define over Garcia of record and Stanley last cited by the Examiner. Neither of these references teach, as required by the claims, a unidirectional antenna comprising a pair

76

of diverging or converging pairs of conductors excited in phase opposition. The fact that these claims have been restricted to a unidirectional antenna, removes the objection that the desired direction of communication may be in all directions. Applicant has carefully considered the Garcia and Stanley patents of record already referred to, but, as already indicated, he fails to find therein any suggestion to the effect that the conductors extend in the desired direction of communication or, in other words, the single direction in which the antenna is to operate; and, moreover, applicant fails to find therein the fact that diverging or converging conductors are excited in phase opposition as required by the claims. Consequently, these claims upon reconsideration should be allowed.

Similar remarks are applicable in favor of claims 10 and 11 over British patent 223,742 which fails, among other things, to teach a unidirectional antenna as required by these claims and moreover it fails to teach the excitation of diverging or converging conductors in phase opposition as called for by claims 10 and 11.

In view of the proof of the operability of applicant's unidirectional antenna system presented herewith in the form of radiation patterns made in the field from an antenna built in accordance with applicant's present invention, claims 1, 3, 12, 13, 14 and 15 should be allowed since no objection other than than the requirement as to proof of operativeness was made against them.

Respectfully,

NILS E. LINDENBLAD

By [signature]
Attorney

HT/AU

1201

Div. 51 Room 340-Annex Paper No. 8

Address only the Commissioner of Patents, Washington, D. C., and not any official by name

All communications respecting this application should give the serial number, date of filing, and name of the applicant

DEPARTMENT OF COMMERCE
UNITED STATES PATENT OFFICE
WASHINGTON

RPM:AH December 14, 1931

Please find below a communication from the EXAMINER in charge of this application.

Thomas E. Robertson
Commissioner of Patents.

Applicant: N. E. Lindenblad

Ser. No. 328,147
Filed Dec. 24, 1928
For Antennas for Radio Communication

H. G. Grover
c/o Radio Corp. of America
570 Lexington Ave.
New York, N. Y.

MAILED
DEC 14 1931

Responsive to amendment of May 5, 1931.

The claims as amended are considered allowable. However, since the numerous insertions in the same lines of claims 6-12, inclusive, renders them confusing it is required that applicant rewrite these claims before the application may be passed to issue.

RPM

C. D. Barnes,
Examiner.

PAPER NO. 9
AMENDMENT C

MAIL DIVISION MAR - 2 32 U.S. PATENT OFFICE

UNITED STATES PATENT OFFICE

APPLICATION OF: NILS E. LINDENBLAD

FOR: ANTENNAS FOR RADIO COMMUNICATION

SERIAL NO.: 328,147 FILED: DECEMBER 24, 1928

DIVISION: 51 ROOM: 240-ANNEX

LAST OFFICE ACTION: DECEMBER 14, 1931.

PATENT OFFICE MAR 2 1932 DIV. 51

New York, N. Y., March 1, 1932.

COMMISSIONER OF PATENTS,

WASHINGTON, D. C.

DEAR SIR:

In response to the Office action of December 14, 1931, claims 6 to 12 inclusive are being rewritten to avoid confusion due to numerous insertions in these claims.

C'

40 ~~6.~~ A uni-directional antenna comprising a gradually diverging pair of conductors excited in phase opposition, diverging and extending longitudinally only in the desired direction of ~~radiant~~ action.

~~7. A uni-directional antenna comprising a gradually diverging pair of conductors excited in phase opposition, diverging and extending longitudinally only in the direction of desired communication.~~

Pat. Fi

50 ~~8.~~ A uni-directional antenna comprising a gradually converging pair of conductors excited in phase opposition, converging and extending longitudinally only in the ~~direction of desired communication.~~ desired direction of radiant action.

Fi

60 ~~9.~~ A uni-directional antenna comprising a pair of conductors excited in phase opposition, extending longitudinally in the desired direction of radiant action ~~direction of desired communication~~, the effective portions of which gradually diverge and converge successively.

Fi

Claim 7: "A uni-directional transmitting antenna comprising a pair of conductors excited in phase opposition, extending longitudinally in the direction of desired transmission, the radiating portions of which gradually diverge and converge successively in the direction of desired transmission."

Margin note beside claim 7: "E cont / Fig. E ..."

Claim 8: "In combination, a two conductor transmission line excited in phase opposition, and an antenna connected thereto extending longitudinally in the direction of transmission, comprising a gradually diverging extension of the conductors of the transmission line at their remote open ends."

Claim 9: "In combination, a two conductor transmission line excited in phase opposition, and an antenna extending longitudinally in the direction of desired radiant action comprising an open ended pair of conductors which at one end are spaced at the spacing of the transmission line and are coupled thereto, and which gradually diverge to a much wider spacing at their open ends."

Handwritten after claim 9: "Ex. W. ... orig."

Margin note: "Checked & approved P.F.W"

Then: "Please add the following claims:"

Claim 13: "A uni-directional antenna comprising a diverging pair of conductors excited in phase opposition, diverging ~~and extending longitudinally~~ only in the desired direction of ~~desired con... conversion~~ radiant action."

Margin notes: "C.2", "Prefix ...", "L"

Claim 14: "A uni-directional antenna comprising a converging pair of conductors excited in phase opposition, converging ~~and extending lon~~gitudinally only in the desired direction of ~~desired communication~~ radiant action."

Margin notes: "L" (twice)

Claim 15: "A uni-directional antenna comprising a pair of conductors excited in phase opposition, extending longitudinally in the desired direction of ~~desired communication~~ radiant action, the effective portions of which diverge and converge successively."

Margin notes: "L", "Insert E: cls 16-23"

Circled at the foot of the page: "(2)".

R E M A R K S

The application has been indicated as being ready to pass for issue, which is respectfully requested at an early date. Claims 6 to 12 in this application have been rewritten to avoid confusion due to numerous insertions. The language in these claims is identical with that appearing in the claims as originally filed with the insertions added in the several previous amendatory papers.

New claims 13, 14 and 15, respectively, are of scope very similar to allowed claims 7, 8 and 9, differing therefrom only in the omission of the term "gradually". These new claims are, therefore, considered to be clearly allowable.

Respectfully submitted,
NILS E. LINDENBLAD

H. G. Grover
Attorney.

CMB:L

7

31

Paper No. 10

Address only "The Commissioner of Patents, Washington, D. C." and not any official by name. KPM:LCG

All communications respecting this application should give the serial number, date of filing, and name of the applicant

DEPARTMENT OF COMMERCE
UNITED STATES PATENT OFFICE
WASHINGTON March 9, 1932.

Please find below a communication from the EXAMINER in charge of this application.

Thomas E. Robertson
Commissioner of Patents.

. G. Grover,
C/o Radio Corp. of America,
570 Lexington Avenue,
New York, N. Y.

Applicant: N. E. Lindenblad
Ser. No. 328,147
Filed Dec. 24, 1928
For Antennas for Radio Communication.

MAILED
MAR 9 1932

Responsive to amendment filed March 2, 1932.

Claims 6-12 as rewritten have been entered. Newly added claims numbered 13-15 in the amendment have been renumbered 17-19 in order that the numbers run consecutively.

New claims 17-19 are rejected as being broader than the invention since it is only shown that applicant's device is operative if the antennae are gradually diverging.

New claims 17-19 are further rejected as unpatentable over allowed claims 7, 8 and 9, respectively, since they are substantial duplicates of the allowed claims, as the word "gradually" must be read into them in order to read them on the disclosure.

Claims 1, 3, and 6-16 stand allowed.

RM

O. D. Backus
Examiner

PAPER NO 11
AMENDMENT D

MAIL DIVISION
MAR - 8 32
U.S. PATENT OFFICE

UNITED STATES PATENT OFFICE

- -

APPLICATION OF: NILS E. LINDENBLAD :

FOR: ANTENNAS FOR RADIO COMMUNICATION :

SERIAL NO.: 328,147 FILED: DECEMBER 24, 1928 :

DIVISION 51 ROOM: 240-ANNEX :

LAST OFFICE ACTION: DECEMBER 14, 1931. :

- -

New York, N. Y., March 5, 1932.

COMMISSIONER OF PATENTS,

WASHINGTON, D. C.

PATENT OFFICE
MAR 9 1932
DIV. 51

DEAR SIR:

This supplements applicant's amendatory paper of March 1, 1932.

It is noted that the new claims added in the amendatory paper above referred to have been designated incorrectly by the reference numerals 13, 14 and 15. It is respectfully requested that the reference numerals of these new claims be changed to 17, 18 and 19.

Respectfully submitted,

NILS E. LINDENBLAD

By H. S. Grover
Attorney.

CHB:EC

PAPER NO. 12
AMENDMENT E

MAIL DIVISION AUG-5 32 U.S. PATENT OFFICE

UNITED STATES PATENT OFFICE

APPLICATION OF: N. E. LINDENBLAD

FOR: ANTENNAS FOR RADIO COMMUNICATION

SERIAL NO.: 328,147 FILED: December 24, 1928

DIVISION: 51 ROOM: 5626

LAST OFFICE ACTION: March 9, 1932.

E

New York, N. Y., August 4, 1932.

COMMISSIONER OF PATENTS

WASHINGTON, D. C.

AUG 8 1932

DEAR SIR:

In response to the Office action of March 9, 1932, please amend the above-entitled application as follows:

Add the following claims:

E[1]

16 ~~20~~. A highly directional antenna system comprising wires which are long relative to the length of the communication wave excited in phase opposition, which first diverge from the excitation end and then converge successively, whereby radiant action occurs predominantly in a direction substantially through the opposite apices of the wires.

17 ~~21~~. A system in accordance with claim 16 ~~20~~, characterized in this, that said wires are in a single vertical plane.

18. ~~22~~. A highly directional antenna system comprising a pair of conductors excited in phase opposition, said wires being long relative to the length of the communication wave and extending in the desired direction of signal action ~~desired communication~~, the effective portions of which diverge and converge successively.

Rev.

Per K

~~18. A unidirectional antenna system comprising a pair of conductors which are long relative to the length of the communication wave, said conductors being excited in phase opposition and arranged to first diverge from the excitation end and then converge, whereby radiant action occurs predominantly in a direction through the excitation end of the wires and the opposite apex.~~

E' cont

19 ~~xx~~. A highly directional antenna system comprising a pair of conductors angularly disposed with respect to each other, said conductors being long relative to the length of the communication wave and ~~open-ended~~, and means for exciting the conductors in phase opposition whereby radiant action occurs predominantly along the direction of the axis of the conductor system.

20 ~~xx~~. A unidirectional antenna system comprising a diverging pair of conductors, the said conductors being long relative to the length of the communication wave, and means for producing traveling waves thereon whereby radiation is predominantly along the approximate direction of the length of the conductor system.

21 ~~xx~~. A system in accordance with claim 20 ~~xx~~ characterised in this, that said conductors are open-ended and disposed in the same vertical plane.

22 ~~xx~~. A directional antenna comprising a diverging pair of conductors which are long relative to the working wave length, and means at adjacent ends of said conductors for energising same in phase opposition, said conductors being arranged to be on the same side of said energising means and to extend away from said energising means whereby radiant action occurs predominantly along the approximate direction of the length of the conductor system.

2~~28~~. A directional antenna comprising a pair of open-ended, diverging conductors which are long relative to the working wave length, and means at adjacent ends of said conductors for energizing same in phase opposition, said conductors being arranged to be on the same side of and to extend away from said energizing means whereby radiant action occurs predominantly in a direction making equal angles greater than zero degrees with reference said conductors.

6 cont

(add G Ch 24)

Sheet Ch 24

REMARKS.

The Examiner's position with respect to new claims 17 to 19 is not considered to be well taken since he presents two grounds of rejection which are inconsistent with respect to each other. If the new claims 17 to 19 are substantial duplicates of allowed claims 7, 8 and 9 then they define a device which is operative. If claims 17 to 19 define a device which is inoperative then allowed claims 7, 8 and 9 also define inoperative devices and should be rejected since their operability is not a mere matter of degree.

Applicant submits, however, that in his opinion new claims 17 to 19 are of somewhat different scope than allowed claims 7, 8 and 9 and do define an operative device of the type disclosed in Figures 1, 2 and 5 of the drawings. The expression "gradually" now present in the allowed claims, it is thought, might be construed merely to cover a method of using only curved wires of the type indicated by reference characters 24 and 28 in Figure 3, whereas the present invention is intended to apply not only to the use of curved wires, but also to straight linear wires such as shown in Figures 2 and 5 and to wires diverging more abruptly in exponential fashion as shown in Figure 1. Applicant is attempting by adding new claims 17 to 19 to adequately define the present

invention in such manner that the claims are clear, definite and unambiguous, and it is only while the application is still pending in the Patent Office and in the formative state that he is able to present such claims. It is feared that if the present application issues with the term "gradually" recited in the allowed claims that some dishonest competitor in a future law suit may contend that his device does not infringe because the expression "gradually" used in the claims should be construed to cover only curved wires, whereas actually applicant is entitled to cover straight linear wires and wires diverging more abruptly in exponential fashion. For this reason it is submitted that new claims 17 to 19 are not substantial duplicates of the allowed claims, but of somewhat broader scope. Devices in accordance with these claims have actually been used with excellent results, as shown by the radiation curves previously submitted by applicant as proof of the operativeness of his invention. Since these new claims 17 to 19 are patentable over the prior art and clearly within the scope of the present invention it is urged that the Examiner should not be too technical and insist upon the use of a term in the claims which might later be construed to be so vague as to cause him irreparable harm when applicant is clearly entitled as a protection for his invention to the omission of such term in order to present claims which are clear, concise and exact.

New claims 20 to 28 are specific to applicant's highly directional antenna system and are limited to conductors arranged to be energized in phase opposition, a feature lacking in the prior art. Further, claims 21 and 26 call for such a system wherein the wires are located in a single vertical plane, a particularly advantageous arr   ment which has been used in the

field. New claim 22 is of scope somewhat similar to allowed claim 9. Claim 23 which recites a unidirectional antenna system whereby radiant action occurs in a direction through the excitation end of the wires, a feature of which the art is silent, is more specific in certain respects than allowed claim 9. New claims 24, 26 and 28 are further specific to open-ended conductors, and new claim 25 is limited to the use of traveling waves.

The art of record does not show either highly directional or unidirectional antennae, and still less, antennae conductors energized in phase opposition with respect to each other. Nor do the references show antenna systems wherein the direction of radiation is along the direction of the axis or length of the conductors.

Claims 1, 3 and 6 to 16 stand allowed.

Allowance of new claims 17 to 19, together with new claims 20 to 28, is respectfully requested so that this application may soon pass for issue.

Respectfully submitted,

N. E. LINDENBLAD

By H. S. Grover
Attorney.

GGR:SS

Div. 51 Room 6436 Paper No. 13

DEPARTMENT OF COMMERCE
UNITED STATES PATENT OFFICE

EBM:ECC WASHINGTON December 7, 1932.

Please find below a communication from the EXAMINER in charge of this application.

Thomas E. Robertson
Commissioner of Patents.

Applicant: N. E. Lindenblad

H. G. Grover,
C/o Radio Corp. of America,
570 Lexington Avenue,
New York, N. Y.

Ser. No. 329,147
Filed Dec. 24, 1928
For Antennas for Radio Communication

MAILED
DEC 7 1932

Responsive to amendments filed March 8 and August 5, 1932.

Upon careful review of this application it is found that claim 7 is a duplicate in structure of allowed claim 6. The only difference in these claims is found in the words used to describe the direction of communication. Accordingly, the allowance of claim 7 is withdrawn and this claim is rejected as unpatentable over claim 6.

Claims 17-19 are again rejected as being broader than applicant's invention since as pointed out in the specification, the antennae must gradually converge or diverge in order to properly operate. This is true whether the divergence is in a straight line or according to an exponential curve.

Claims 17-19 are again further rejected as unpatentable over allowed claims 6, 8, and 9 since if modified by the necessary qualification of "gradually" they are identical with these claims in structure.

Claims 20-23, inclusive, are rejected as being broader than the invention since as pointed out in connection with claims 17-19, it is necessary to specify that the radiating conductors "gradually" diverge and converge.

Moreover, claims 20-23 are all duplicates of each other in structure.

O. D. Becker
Examiner

P.M.

PAPER No. 14
AMENDMENT F

MAIL DIVISION
JAN - 3 33

UNITED STATES PATENT OFFICE

APPLICATION OF: N. E. LINDENBLAD

FOR: ANTENNAS FOR RADIO COMMUNICATION

SERIAL NO.: 328,147 FILED: December 24,1928

DIVISION: 51 ROOM: 5628

LAST OFFICE ACTION: December 7, 1932.

PATENT OFFICE
JAN 4 1933
DIV 51 FILED

New York, N. Y., December 30, 1932.

COMMISSIONER OF PATENTS

WASHINGTON, D. C.

DEAR SIR:

In response to the Office action of December 7, 1932. please amend the above-entitled application as follows:

Cancel claim 7.

Claim 8, last two lines, and claim 9, line 3, change "direction of desired communication" to --desired direction of radiant action--.

Claims 17 and 18, line 2, cancel "and";

line 3, cancel "extending longitudinally";

after "the" insert --desired--;

lines 3 and 4, cancel "desired communication" and substitute therefor --radiant action--.

Claim 19, line 3, after "the" first occurrence insert --desired--;

cancel "desired communication" and substitute therefor --radiant action--.

Claim 22, line 4, after "the" first occurrence insert --desired--;

cancel "desired communication" and substitute therefor --radiant action--.

Cancel claim 23.

REMARKS.

In accordance with the interview kindly granted applicant's attorney the above-entitled application is being amended in a manner which, it is believed, will place it in condition for allowance.

Claims 7 and 23 have been cancelled without prejudice merely because it is thought that the subject matter thereof is adequately protected by the remaining claims of this application.

Claims 8, 9, 17, 18, 19 and 22 have been amended in the interest of clarity to recite that the conductors either diverge or converge, depending upon the wording of the respective claims, in the desired direction of radiant action. These amendments, it is thought, render the claims more concise and accurate than before.

Claims 8 and 9, it should be noted, are allowed. The amendments to these claims, it is thought, do not render them unpatentable. It is requested that these claims remain allowed.

The objection to claims 17 to 19 and 20 to 23 by the Examiner, due to the omission of the expression "gradually", has been discussed at the oral interview and, as agreed, is considered not to be well taken. The present invention is not limited in scope to any gradual divergence or convergence since it covers a wide range of departure from the parallel condition of two straight wires, this range extending up to, but not including the well known 180 degree spaced dipole antenna. The specification as originally filed, in various parts thereof, is believed to adequately support this contention, attention being particularly invited to page 8 of the specification, the first paragraph thereof, which expressly states that although the preferred embodiment utilizes a gradual divergence, still this divergence is variable over a great range. A fair reading of the last

5

paragraph of page 4 of the application also implies that this spacing does not depend upon gradual convergence, inasmuch as the divergence must be more than gradual to obtain any sort of desired radiant action if the antenna circuit is relatively short.

As regards the Examiner's statement that claims 20 and 22 are duplicates of each other, it is respectfully submitted that these the claims are not identical in scope, but differ in that claim 22 recites not only a pair of conductors, a limitation lacking in claim 20, but also omits reference to the excitation end of the antenna system, a limitation which is called for by claim 20. The omission of this particular feature from claim 22 is believed to render this claim slightly broader in scope than claim 20 and to be one which is necessary to give applicant the protection for his invention to which he is clearly entitled.

Claims 1, 3,6 and 8 to 16 inclusive stand allowed.

Allowance of claims 17 to 19, 20 and 22, and 24 to 28 inclusive is now believed to be in order, and allowance is, therefore, requested so that this application may pass for issue.

Respectfully submitted,

N. E. LINDENBLAD

By H G Grover
Attorney.

GHB:DG

Div. 51, Room 5628

Serial No. 588,147

Department of Commerce

United States Patent Office

Nils E. Lindenblad, Assor. Washington February 23, 1933.
to Radio Corporation of America, a Corp. of Delaware.

Your APPLICATION for a patent for an IMPROVEMENT in ANTENNAS FOR RADIO COMMUNICATION

filed Dec. 24, 1932 has been examined and ALLOWED with [illegible] claims.

The final fee, THIRTY DOLLARS, WITH $1 ADDITIONAL FOR EACH CLAIM ALLOWED IN EXCESS OF 20, must be paid not later than SIX MONTHS from the date of this present notice of allowance. If the final fee be not paid within that period, the patent will be withheld, but the application may be renewed within one year after the date of the original notice with a renewal fee of $30 and $1 additional for each claim in excess of 20.

The office delivers patents upon the day of their date, on which date their term begins to run. The preparation of the patent for final signing and sealing will require about four weeks, and such work will not be begun until after payment of the necessary final fee.

When the final fee is paid, there should also be sent, DISTINCTLY AND PLAINLY WRITTEN, the name of the INVENTOR, TITLE OF THE INVENTION, AND SERIAL NUMBER AS ABOVE GIVEN, DATE OF ALLOWANCE (which is the date of this circular), DATE OF FILING, and, if assigned, the NAMES OF THE ASSIGNEES.

If it is desired to have the patent issue to an ASSIGNEE OR ASSIGNEES, an assignment containing a REQUEST to that effect, together with the FEE for recording the same, must be filed in this office on or before the date of payment of the final fee.

After issue of the patent, uncertified copies of the drawings and specifications may be purchased at the price of TEN CENTS EACH. The money should accompany the order. Postage stamps will not be received.

The final fee will NOT be received from other than the applicant, his assignee or attorney, or a party in interest as shown by the records of the Patent Office.

NOTICE.—WHEN THE NUMBER OF CLAIMS ALLOWED IS IN EXCESS OF 20, NO SUM LESS THAN $30 PLUS $1 ADDITIONAL FOR EACH CLAIM IN EXCESS OF TWENTY CAN BE ACCEPTED AS THE FINAL FEE.

Respectfully,

Thomas E. Robertson

Commissioner of Patents.

H. G. Grover,
C/o Radio Corp. of America,
570 Lexington Avenue,
New York, N. Y.

SENT IN REMITTING THE FINAL FEE GIVE THE SERIAL NUMBER AT THE HEAD OF THIS NOTICE.

UNCERTIFIED CHECKS WILL NOT BE ACCEPTED.

DEPARTME OF COMMERCE
UNITED STATES PATENT OFFICE
WASHINGTON

June 20, 1933

Petition under **RULE 78:**

Application of

Serial No.

Invention:

This petition is referred to Examiner in charge of Division 51 in accordance with Order No. 2098; Order No. 2801, 300 O. G., 447, and Notice of August 11, 1922.

Thomas E. Robertson
Commissioner.

1006

1218

PAPER NO 15
AMENDMENT 4
(R 78)

UNITED STATES PATENT OFFICE

APPLICATION OF: N. E. LINDENBLAD

FOR: ANTENNAS FOR RADIO COMMUNICATION

SERIAL NO.: 328,147 FILED: December 24,1928

DIVISION: 51 ROOM: 5626

U. S. PATENT OFFICE
JUN 19 1933
ISSUE DIVISION

MAIL DIVISION
JUN 16 33

Allowed Feb. 23 1933

New York, N. Y., June 14, 1933.

COMMISSIONER OF PATENTS

WASHINGTON, D. C.

PATENT OFFICE
JUN 20 1933
DIV. FILED

DEAR SIR:

Please amend the above-entitled application under the provisions of Rule 78 as follows:

Claims 24, 25 and 27, last line, singularize "conductors" and add thereafter the word --system--.

Add the following claim:

28. A highly directional antenna system comprising a pair of electrical conductors which are disposed at an angle with respect to each other and serially connected together, said conductors having an overall length which is long relative to the operating wave length, high frequency apparatus, and means for connecting said apparatus to one end of one of said conductors, the other end of said connected conductor being connected to one end of the second conductor of said pair whereby high frequency energy flows through the entire length of one conductor and continues serially through the entire length of the other conductor, the conductors being adjusted in length and impedance so that radiant action occurs principally in the direction of a line perpendicular to the bisector of the angle between said conductors.

R E M A R K S.

Claims 24, 25 and 27 have been amended in the interest of clarity to improve their form and to more adequately describe the idea set forth by the invention. Since the scope of these claims has not been changed one iota by this amendment it is thought that no objection will be raised with regard to the admission of this amendment, which is requested under the provisions of Rule 78.

One new claim 29 has been added which is quite specific to applicant's invention. This claim is directed to a system such as is illustrated by the upper half of Figure 8 wherein two serially connected conductors angularly disposed with respect to each other are connected to phase adjusters such as 40. The image of a system with merely the upper half would give a complete system including the lower conductors 23 and 24, as shown, and thus would completely include each and every element of applicant's arrangement. This claim is intended to protect applicant's contribution to the art which might thus be avoided by others who could otherwise utilize with impunity the teachings of applicant's invention by, for example, arranging the antenna conductors in a vertical plane and leaving off the lower half of the system. Applicant contemplates a vertical arrangement as being within the scope of his invention and describes same on page 7, second and third paragraphs of his specification. In view of the specific nature of this claim, which distinguishes over the disclosures of all other references by reciting, in a highly directional antenna system, such limitations as the serial flow of high frequency energy along conductors which are angularly disposed with respect to each other, and obtaining by means of desired length and impedance values radiant action in a direction of a line perpendicular to the bisector of the angle between the conductors, this claim, it is thought, is clearly allowable and such action is earnestly requested.

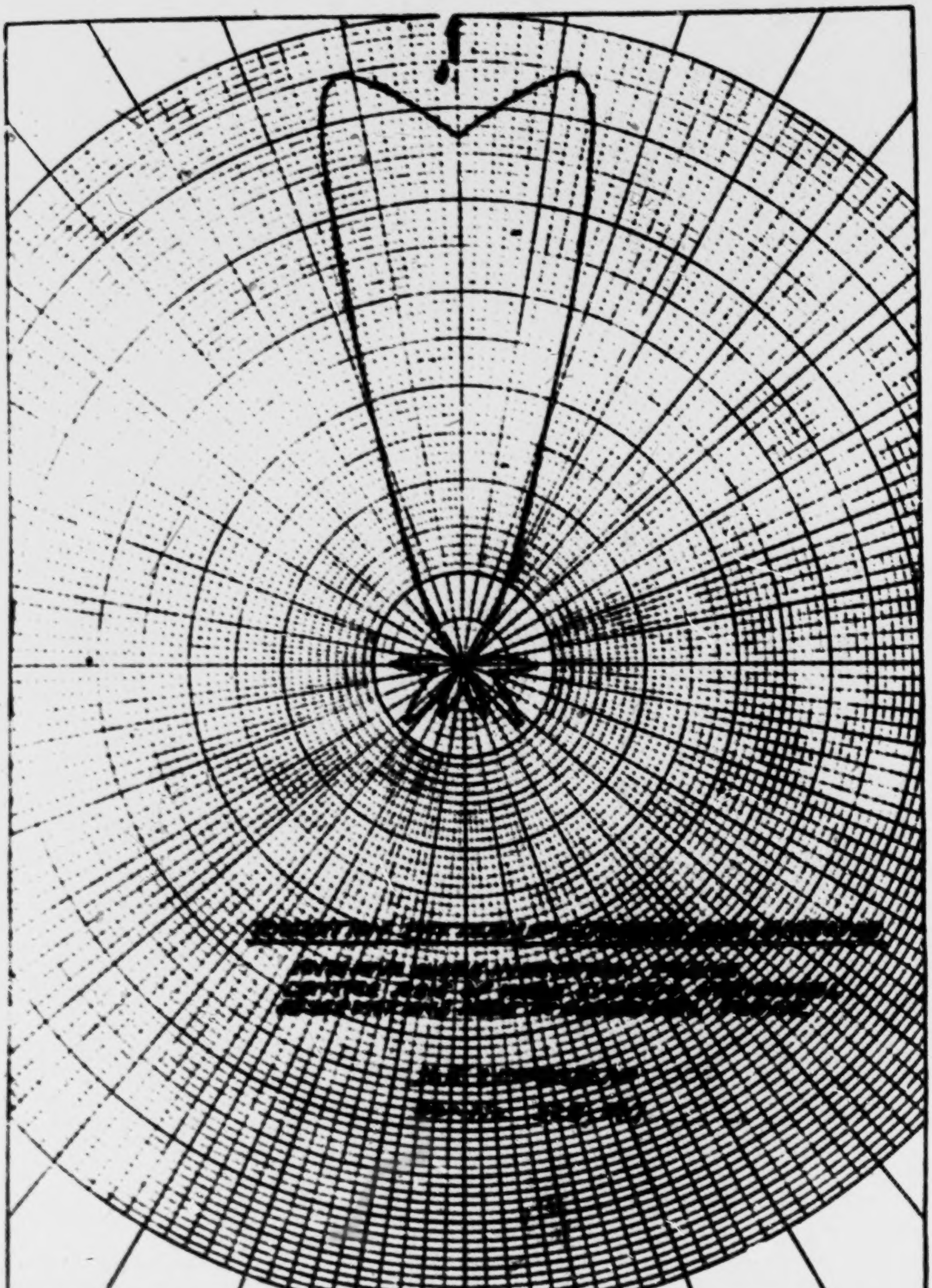
Early and favorable consideration of this amendment and its entrance under the provisions of Rule 78 is earnestly requested so that the application may soon pass for issue.

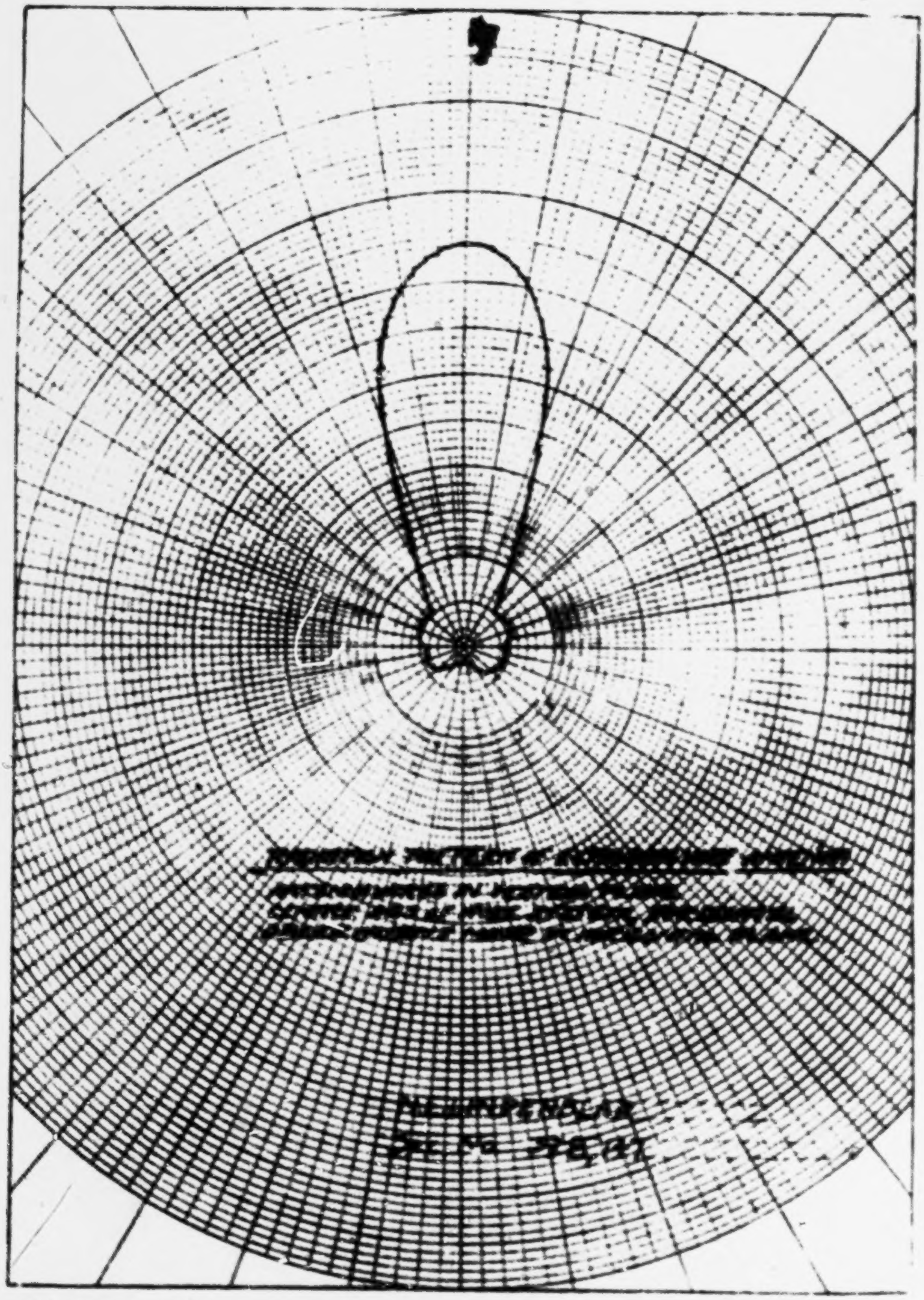
Respectfully submitted,

N. E. LINDENBLAD

By W. G. Grover
Attorney.

CHG:EC





Div. 51 Room 3688 Paper No. 16

DEPARTMENT OF COMMERCE
UNITED STATES PATENT OFFICE
WASHINGTON

[redacted]:MCG June 21, 1933.

Applicant: N. E. Lindenblad

Ser. No. 328,147
Filed Dec. 24, 1928
For Antennas for Radio Communication.

H. G. Grover,
C/o Radio Corp. of America,
570 Lexington Avenue,
New York, N. Y.

The entry of the amendment proposed under Rule 78 has been disapproved in part. A copy of the examiner's adverse report appears below.

Thomas E. Robertson

Commissioner of Patents.

Responsive to amendment filed June 16, 1933.

The amendment to claims 24, 25 and 27 has been entered.

The proposed claim has not been entered since it is not apparent that an incomplete portion of the antenna as claimed herein would operate to give the desired result, particularly since no support for this change in the system is found in the specification.

K M

Leo P. McCann
Acting Examiner

APPROVED
JUN 22 1933
[signature]
ASST. COMMISSIONER OF PATENTS.

DEPARTMENT OF COMMERCE
UNITED STATES PATENT OFFICE
WASHINGTON

Aug. 7, 1933

Petition under **RULE 78:**

Application of

Serial No.

Invention:

This petition is referred to Examiner in charge of Division 51 in accordance with Order No. [illegible]; Order No. [illegible], [illegible] O. G., 447, and Notice of August 11, [illegible].

[illegible]

Commissioner.

NOTICE IS HEREBY GIVEN THAT I HAVE CHANGED MY ADDRESS TO

30 ROCKEFELLER PLAZA

NEW YORK, N. Y.

H. G. GROVER

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1013

U.S. PATENT OFFICE

AUG 5 - 1933

UNITED STATES PATENT OFFICE

AUG 7 1933

APPLICATION OF: N. E. LINDENBLAD

FOR: ANTENNAS FOR RADIO COMMUNICATION

SERIAL NO.: 328,47 FILED: December 24,1928

DIVISION: 51 ROOM: 5628

LAST OFFICE ACTION: June 21, 1933.

New York, N. Y., August 3, 1933.

COMMISSIONER OF PATENTS

WASHINGTON, D. C.

DEAR SIR:

Reconsideration of the Examiner's refusal to enter proposed claim 29 under the provisions of Rule 78 is respectfully requested.

The statement of the Examiner that it is not apparent that an incomplete portion of the antenna as claimed therein would operate to give the desired result has been noted and applicant submits herewith a photostatic copy of a letter received from the inventor as proof that such an arrangement as defined in the claim will inherently function. It is earnestly submitted that the operation of such an arrangement should be obvious to anyone skilled in the art from a mere reading of applicant's disclosure and is a very natural detail of the system described. As appears in the attached letter, to which the Examiner's attention is respectfully invited, the theory of images as first developed by Lord Kelvin has time and again been used and proved, especially in the radio art and also in other branches of the electrical art.

The attached letter, it is submitted, is indeed persuasive evidence, and is considered to be sufficient proof, that the system of the proposed claim does inherently function as

328147

stated, and is a very natural detail of the system, obvious to anyone skilled in the art.

In view of the foregoing, it is submitted that claim 2 defines an arrangement to which applicant is clearly entitled and one which is necessary to give him the protection he needs for his invention.

Applicant at this time wishes to thank the Examiner for the very courteous interview kindly granted to him.

Respectfully submitted,

N. E. LINDENBLAD

By H. G. Grover
Attorney.

Cl. 29 in paper 15

ENTRY RECOMMENDED
UNDER RULE 78.

D. D. Backus
EXAMINER

GHD:BG
Enclosure.

Approved
JJ PPm

R.C.A. COMMUNICATIONS, INC.

INTERDEPARTMENT CORRESPONDENCE

TO	Mr. C. H. Brown, Patent Dept.	PLACE	Rocky Point, New York
		DATE	July 24, 1933
FROM	Mr. N. E. Lindenblad	FILE No.	I-100
SUBJECT	Lindenblad Docket 2961		

PATENT DEPARTMENT
RECEIVED
JUL 25 1933
ANSWERED ________

Dear Mr. Brown:

I have your letter of July 17, 1933 calling my attention to the fact that the Examiner has raised some question with regard to the operativeness of the system defined in our claim 29 which was proposed under Rule 78, wherein merely the upper half of the system of our Figure 5 may be used with an image in the ground.

It is surprising that the Examiner has raised this question since the operation of such an arrangement should be obvious to anyone skilled in the art and to be a very natural detail of the system.

I believe it requires no argument that one half of the system with an image in the ground functions as is claimed to obtain radiant action principally in the direction of a line perpendicular to the bisector of an angle between the conductors of half the system. The theory of images as first developed by Lord Kelvin has time and again been used and proved, especially in the radio art and also in other branches of the electrical art. It is one of the axioms on which we build our theories of propagation and is an accepted fact. Thus, for instance, in the case of a half wave doublet away from any reflecting or image surface we have a radiation resistance of about 72 ohms. If we now cut our doublet at the middle and take such a half and place it at right angles with a reflecting surface, letting one end of the wire touch the surface, we have a quarter wave antenna of exactly half the radiation resistance. This is a widely used arrangement in the broadcasting field. In many instances, especially at the longer waves, when for instance the dimensions of such a wire would call for unreasonably high supporting structures, extra capacity is added at the top and extra inductance is added at the bottom in order to permit tuning. In the calculation of any of these systems, the procedure is, however, always the same; the consideration of the image. When, for instance, the capacity of an antenna is calculated, it is calculated between the real structure and its image. The surface of the ground is then the symmetrical dividing surface. The capacity obtained by calculating in this manner is then considered as consisting of two capacities in series, the one between the real structure and the surface and the other between the surface and the image. The actual capacity is then the capacity of one of these, or twice the capacity of the two in series. The calculation of radiation resistance applies identical reasoning. The radiation resistance of a doublet is 72 ohms. If half of such a doublet is an image, the actual system,

which is then only a quarter wave radiator, has half the radiation resistance; the value of one of two resistances in series. In most cases the reflecting, or image forming surface, which is earth itself, is, of course, not perfect. Therefore certain deviations take place which have to be taken into account. This, however, does not detract from either the general theory or the results. They are only correction factors.

Now in case of our particular antenna system. It is a symmetrical structure around the axis of maximum radiation. If we therefore locate a conductive plane to include this axis and also to be at right angles with the plane of the wires we have in no way disturbed the system. The conductive plane is in a neutral region. The two halves, one on each side of the plane, are in series. If we now throw away one half and let earth itself be the conductive plane, we have the antenna system set forth in your proposed claim. ~~Such an arrangement is in accordance with the principles of our invention and will inherently function as we state in the claim.~~ The total radiation resistance of such a system will then be one half of the radiation resistance of the double system, save for the corrections that will have to be made for the imperfection of the soil.

I hope the above will aid you in clearing up the objection raised by the Examiner since we are clearly entitled to a claim such as we propose covering the very obvious and natural detail of our general system utilizing an image in the ground.

If the above explanation does not suffice, I shall be very happy to supply further proof, either by affidavit or of a mathematical nature, that the system defined in the claim functions correctly and as we propose. However, in view of the fact that the theory of operation of the system has been proven time and time again, as I have mentioned before, and is so well known to all engineers, I hardly think that further proof will be required to prove our contention.

Very truly yours

N. E. Lindenblad

NEL/MVN

N. E. Lindenblad

1017

Div. 51 Room 5628

Address only "The Commissioner of Patents, Washington, D. C." and not any official by name

RFM:B

DEPARTMENT OF COMMERCE
UNITED STATES PATENT OFFICE
WASHINGTON

Paper No. 18

All communications respecting this application should give the serial number, date of filing, and name of the applicant.

August 11, 1938

H. G. Grover
C/o Radio Corp of America
30 Rockefeller Plaza,
New York, N.Y.

Applicant: Nils E. Lindenblad

Ser. No. 328,147
Filed Dec. 24, 1928
Forintennas For Radio Communication

The amendment proposed has been entered under Rule 78.

Conway P. Coe
Commissioner of Patents.

THE FINAL FEE WILL NOW BE $84.00

DEPARTMENT OF COMMERCE
UNITED STATES PATENT OFFICE
WASHINGTON

Aug. 17, 1938

Petition under **RULE 78:**

Application of

Serial No.

Invention:

This petition is referred to Examiner in charge of Division 51 in accordance with Order No. 2998; Order No. 2901, 306 O. G., 447, and Notice of August 11, 1932.

Conway P. Coe
Commissioner.

1018

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PAPER NO. 19
AMENDMENT H
U. S. PATENT OFFICE
AUG 17 1933

AUG 17 33

UNITED STATES PATENT OFFICE

- -

APPLICATION OF: N. E. LINDENBLAD

FOR: ANTENNAS FOR RADIO COMMUNICATION

SERIAL NO.: [illegible],147 FILED: DEC. 24, 19[illegible]

DIVISION [illegible] ROOM [illegible]

- -

PATENT OFFICE
AUG 17 1933

New York, N. Y., August 15, 1933

COMMISSIONER OF PATENTS,

WASHINGTON, D. C.

DEAR SIR:

Please amend the above-entitled application under the provisions of Rule 78 as follows:

✓Page 7, after the third paragraph, add the following paragraph:

¶ In connection with Figures 3 and 5, the desired radiation will, of course, take place in the direction of the axis of the transmission line 24 and the diverging conductors. Taken from another point of view, we can consider merely the upper half of Figures 3 and 5 as being in a vertical plane with its image in the ground; we will then have two serially connected conductors (conductor 26 and the upper antenna leading to transmission line 24 in Figure 5). Radiation will occur substantially in the direction of a line perpendicular to the bisector of the angle between these two conductors.

H'

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REMARKS

Applicant is submitting herewith a short paragraph for insertion in the application under the provisions of Rule 78 in order to amplify and clarify the specification. No objection, it is thought, will be raised to the entrance of this amendment which is clearly within the scope of the invention; which is respectfully requested.

Respectfully submitted,

N. E. LINDENBLAD

GHD:B

By [illegible]
Attorney

[illegible]

ENTRY RECOMMENDED
UNDER RULE 78

[illegible]
EXAMINER

[illegible]

[illegible]
[illegible]

Div. 51 Room 5628

Address only "The Commissioner of Patents, Washington, D. C." and not any official by name

MCC

DEPARTMENT OF COMMERCE
UNITED STATES PATENT OFFICE
WASHINGTON

Paper No. 20

All communications respecting this application should give the serial number, date of filing, and name of the applicant.

August 18, 1939.

Applicant N. E. Lindenblad

Ser. No. 323,147
Filed Dec. 24, 1938
For Antennas for Radio Communication.

H. G. Grover,
C/o Radio Corp. of America,
30 Rockefeller Plaza,
New York, N. Y.

The amendment proposed has been entered under Rule 78.

Conway P. Coe ~~Thomas E. Robertson~~
Commissioner of Patents.

AUG 23 33 033 013 A - Check — 30.0

RECD AUG 23 33 033 013 A - Check U.S. Patent Office A.C.

MAIL DIVISION AUG 23 33

U. S. Patent Office

UNITED STATES PATENT OFFICE

APPLICATION OF: N. E. Lindenblad

FOR: Antennas for Radio Communication

SERIAL NO: 320,147 FILED: Dec. 24, 1929

DATE OF ALLOWANCE: Feb. 23, 1933

August 22, 1933

Hon. Commissioner of Patents

Washington, D. C.

Sir:

We are sending you herewith a check number 90105, for $34.00 to pay the final fee on the above identified application.

Respectfully,

N. E. LINDENBLAD

by H G Grover
Attorney

Radio Corporation of America
30 Rockefeller Plaza
New York

AGG:MM
ENCL.

Div. 51 Room 5628

DEPARTMENT OF COMMERCE
UNITED STATES PATENT OFFICE
WASHINGTON

Paper No. 21

All communications respecting this application should give the serial number, date of filing, and name of applicant.

Address only "The Commissioner of Patents, Washington, D. C." and not any official by name.

RR:1106

September 6, 1938

Please find below a communication from the EXAMINER in charge of this application

Commissioner of Patents.

Applicant N. E. Lindenblad

Ser. No. 328,147
Filed Dec. 24, 1928
For Antenna for Radio Communication.

SEP 9 1938

H. G. Grover,
C/o Radio Corp. of America,
30 Rockefeller Plaza,
New York, N. Y.

In accordance with the provisions of Order No. 2308, dated March 12, 1917, which reads in part as follows:

* * * * * * * *

> Obvious informalities in the application may be corrected by the examiner, but said correction must be in the form of an amendment, approved by the Principal Examiner in writing, placed in the file, and made a part of the record. The changes specified in the amendment will be entered by the clerk in the regular way.

* * * * * * * *

the changes, hereinafter specified, are made by the examiner in the application above identified.

Should these changes not be satisfactory to the applicant, appropriate amendment may be proposed under the provisions of Rule 78, provided the specification has not been printed.

The application has been amended as follows:

(original claim 10)
/ In claim 7,/line 3, "directional" has been changed to direction.

RM

Examiner

APR 24 1934

Form No.

District Court of The United States

Eastern District of New York

Honorable Commissioner of Patents,
Washington, D. C.

Sir:

In compliance with the Act of February 18, 1922 (42 Stat. L. 392), you are advised that there was filed on the 21st day of April, 1934 in this court an action, suit, or proceeding No. E 7234, entitled:

Name Radio Corp. of America, Plaintiff,

Address Delaware Corp.

versus

Name Mackay Radio & Telegraph Co Inc., Defendant,

Address Suffolk Co., N.Y.

M.

brought upon the following patents:

PATENT NO.	DATE OF PATENT	PATENTEE
1. 1,623,996	April 10 1927	Philip S. Carter
2. 1,909,610	May 16 1933	Philip Searle Carter
3. 1,884,006	Oct 25 1932	Nils E Lindenblad
4. 1,927,522	Sept 19 1933	
5.		

In the above-entitled case, on the ______ day of ______, 193 , the following patents have been included by ______ (insert amendment, answer, cross bill, or other pleading):

PATENT NO.	DATE OF PATENT	PATENTEE
1.		
2.		
3.		
4.		
5.		

In the above-entitled case the following decision has been rendered or decree issued:

IN WITNESS WHEREOF I have affixed my hand this 23rd day of April, 1934 at Brooklyn N.Y.

Clerk of said Court.

By [initials]

Deputy Clerk

63

51 23

TITLE REPORT

No. 1,987,522

Name N. E. Lindenblad

The title appears from the assignment records to be vested in:

Radio Corporation of America, a corp. of Del.

Examined up to and including 5/23/34

This certificate dated 6/2/34

C. H. Gray

Chief of Assignment Division.

No further assignments appear to have been received for record including 6/20/34

64

1237

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INTERFERENCE

Interference No. 68973 *Paper No.* 24 /

Name, Nils E. Lindenblad

Serial No. 328,147 - Pat. No. 1,927,522

Title, Antennas for Radio Communication

Filed, December 24, 1928 - Pat'd. Sept 19, 1933

Interference with Edmond Bruce

DECISIONS ON MOTION

Ex'r of Interferences, ______ *Dated,* ______

Board of Appeals, ______ *Dated,* ______

DECISIONS ON PRIORITY

Ex'r of Interferences, ______ *Dated,* ______

Board of Appeals, ______ *Dated,* ______

Court, ______ *Dated,* ______

REMARKS:

This should be placed in each application or patent involved in interference in addition to the interference letters by Primary Examiner.

1026

1238

(Fer. Intf. Div., June 12, 1934)

No. 51 Room 5628

Paper No. 25

DEPARTMENT OF COMMERCE
UNITED STATES PATENT OFFICE
WASHINGTON

Please find below a communication from the EXAMINER in charge of this application

Commissioner of Patents

Applicant: N. E. Lindenblad

H. G. Grover,
C/o Radio Corp. of America,
30 Rockefeller Plaza,
New York, N. Y.

MAILED AUG 9 1934

Ser. No. 328,147
Filed Dec. 24, 1928
Antenna for Radio Communication.
Patent No. 1,987,882, granted Sept. 19, 1933.

The case, above referred to, is forwarded to the Examiner of Interferences because it is adjudged to interfere with others, hereafter specified. The question of priority will be determined in conformity with the Rules. The interference will be identified

as No. 68973 On or before SEP 4 1934

the statement demanded by rule 110 must be sealed up and filed with the subject of invention, and name of party filing it, indorsed on the envelope. The subject-matter involved in the interference is

1. A uni-directional antenna comprising a diverging pair of conductors excited in phase opposition, diverging only in the desired direction of radiant action.

2. A highly directional antenna system comprising wires which are long relative to the length of the communication wave excited in phase opposition, which first diverge from the excitation end and then converge successively, whereby radiant action occurs predominantly in a direction substantially through the opposite apices of the wires.

3. A uni-directional antenna system comprising a diverging pair of conductors, the said conductors being long relative to the length of the communication wave, and means for producing traveling waves thereon whereby radiation is predominantly along the approximate direction of the length of the conductor system.

4. A highly directional antenna system comprising a pair of electrical conductors which are disposed at an angle with respect to each other and serially connected together, said conductors having an overall length which is long relative to the operating wave length, high frequency apparatus, and means for connecting said apparatus to one end of one of said conductors, the other end of said connected conductor being connected to one end of the second conductor of said pair whereby high frequency energy flows through the entire length of one conductor and continues serially through the entire length of the other conductor, the conductors being adjusted in length and impedance so that radiant action occurs principally in the direction of a line perpendicular to the bisector of the angle between said conductors.

The interference involves your patent above identified;

and

SHEET NO. 2. 288,147

An application for Directive Antenna, filed by Edmond Bruce, whose Post-Office address is 27 Buena Place, Red Bank, New Jersey, whose attorneys are John G. Roberts and Elmer V. Griggs, 463 West Street, New York, N. Y., whose associate attorney is G. T. Morris, 463 West Street, New York, N. Y., and whose assignees are Bell Telephone Laboratories, Inc., of New York, N. Y., a Corporation of New York.

The relation of the counts of the interference to the claims of the respective parties is as follows:

Counts:	Lindenblad	Bruce
1	15	17
2	16	18
3	20	19
4	24	20

Examiner

1974387

NUMBER (Series of 1925)

360467

DIV. 51

1930

PATENT NO.

DATED SEP 18 1934

(EX'R'S BOOK) 76 92 6

Name PHILIP STAATS CARTER,

Ass(r) to Radio Corporation of America, a corp. of Delaware

PORT JEFFERSON, ~~L I~~

State of Invention NEW YORK

ANTENNAE

ORIGINAL		RENEWED
APPLICATION FILED COMPLETE	JUNE 11 1930	.53
Petition, Specification, Oath, First Fee	JUNE 11 1930	
1 sheet Drawings		
2 EXTRA CLAIMS	JUNE 11 1930	

Examined and passed for issue Jun. 1934 — Exr. Div. 51

Notice of Allowance Jun. 13 1934

Final Fee $21 & 30 Aug 23 1934

Attorney H. G. GROVER C/O RADIO CORP OF AMERICA ~~233 BROADWAY~~ 30 Rockefeller Plaza NEW YORK N Y

~~570 Lexington Ave.~~

Associate Attorney

No. of Claims Allowed 91 Print Claims 3 In O. G. Class 250-33

Title as Allowed Antenna

SPECIAL

CASE PENDING OVER 3 YEARS

1930

CONTENTS:

Application	1	[illegible] O.K.	26.	
[illegible]		March 3, 1931	27.	
Cty. of Adv.		Apr 23 1931	28.	
Amendt A		Sept 2 1931	29.	
Amendt B		Nov 12 1931	30.	
Reg.		Mar 2 1932	31.	
Amendt C		Aug 6 1932	32.	
Reg.		Dec 5, 1932	33.	
Amendt D		May 9 1933	34.	
[illegible] Letter		Aug 8, 1933	35.	
AMENDMENT	E	JAN 18 1934	36.	
AMENDMENT	F	FEB 10 1934	37.	
Reg.		April 11, 1934	38.	
AMENDMENT	G	May 3 1934	39.	— date
Amdt	H	May 15 1934	40.	
Duplicate amendt	I	May 17, 1934 [illegible]	41.	
Amendt J [illegible]		July [illegible] 1934	42.	
[illegible]		July 16, 1934	43.	
Amendment	K	Aug 3 1934	44.	
Notice of Entry		Aug. 16 1934	45.	10'
Amendt	L	Aug 22, 1934	46.	
Notice of Entry		August 23 1934	47.	
			48.	
			49.	
			50.	

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27.00

JUN 1? 30

C.R.U.S. PAT. OFFICE

12

460467

PATENT OFFICE

JUN 18 1930

FILED

PETITION

TO THE HONORABLE COMMISSIONER OF PATENTS:

Your petitioner, PHILIP STAATS CARTER

a citizen of the United States, residing at Port Jefferson, Long Island.

in the County of Suffolk State of New York

whose Post Office address is Port Jefferson, Long Island, New York.

prays that Letters Patent may be granted him for the improvement in

77 ANTENNAS

set forth in the accompanying specification.

And he further prays that you will recognize H. G. Grover, care of Radio Corporation of America, 233 Broadway, New York, as his attorney, with full power of substitution and revocation, to prosecute this application, to make alterations and amendments therein, to receive the patent, and to transact all business in the Patent Office connected therewith.

Philip S. Carter

SPECIFICATION

TO ALL WHOM IT MAY CONCERN:

BE IT KNOWN THAT I, PHILIP STAATS CARTER, a citizen of the United States, and a resident of Port Jefferson, Long Island, New York, have invented certain new and useful improvements in

ANTENNAE

of which the following is a specification:

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This invention relates to antennae and especially to directional antennae or antennae systems.

If a wire long, relative to the working wave length; namely, a plurality of half wave lengths long, is excited in a fashion such that standing waves are ~~produced thereon~~, radiation will occur principally in the direction of symmetrical cones having their apices at the center of the wire. In cross section, the radiation characteristic would appear as symmetrical hollow cones about the wire.

An object of the present invention is to utilize this phenomenon for the directive radiation of electromagnetic energy. To do so, a pair of wires or linear conductors long relative to the working wave length are disposed at an angle such that principal radiation takes place along the bisector of the angle. This angle, in general, corresponds to the angle of the principal cone of radiation about one of the conductors.

Still a further object of the present invention is to disclose the proper angle for conductors or radiators either an even number of half wave lengths long or an odd number of half wave lengths long, and, in general to disclose the angle for best directional propagation for wires of any finite length.

A pair of conductors disposed in the manner described will radiate equally well in two directions, namely, towards the diverging end of the wires and towards the converging end of the wires. That is to say, the antenna system so far described is bidirectional.

A further object of the present invention therefore is to provide a unidirectional arrangement. This may preferably be ~~is~~ accomplished by placing a similar parallel pair of wires an odd number of quarter wave lengths away from the wires forming the antenna proper in a direction taken along the bisector of the angle formed by the wires. The second pair of wires may be left unenergized or floating, or they may be energized in proper phase such that for one direction radiation cancellation occurs, whereas in the other direction there is a strengthening of propagated electromagnetic waves.

A still further object is to ~~To~~ concentrate the beam in a transverse plane, relative to the plane of the pairs of wires, (which is usually the vertical plane, since the pairs are ordinarily disposed in horizontal planes.) ~~is a further object of the present invention;~~ and this is accomplished by placing similar pairs of wires in planes parallel to the planes of the first mentioned pair of wires the planes being spaced apart, preferably, at least a half wave length.

In order to further ~~To additionally~~ concentrate the beam of energy radiated, systems of the nature outlined above ~~hereinbefore~~ may be placed in broadside whereby there is added concentration of the radiated beam of energy in a horizontal plane, and, by placing more systems or stories of systems above one another, there will be added concentration of a beam in a vertical plane.

The invention is further described in connection with the accompanying drawing, in which

Figure 1a illustrates, generally, the principal ~~conic~~ conical radiational characteristic of a long conductor upon which standing waves are produced,

Figure 1b illustrates in cross section, the radiation characteristic of a wire five wave lengths long,

Figures 2a, 2b an 2c indicate various forms of the fundamental unit of the present invention wherein long linear conductors having standing waves thereon are disposed at an angle such that principal radiation occurs along the direction of the bisector of the angle,

Og Figure 3 indicates the bidirectional characteristic of one of the units shown in any of the figures 2a, 2b, or 2c ~~figure 2.~~

g Figure 4 illustrates an antenna system for concentrating the directional beam radiated from one of the units shown in figures 2a, 2b and 2c ~~figure 2,~~

Figure 5 illustrates the arrangement of a plurality of units such as shown in figure 2 for obtaining unidirectional propagation,

g g Figures 6 and 7 illustrate, respectively, the power distribution in the horizontal and vertical planes from ~~an antenna system such as shown in figure 5,~~ one antenna system of particular dimensions of the type shown in figure 5,

Figure 8 illustrates a broadside arrangement of unidirectional units for further increasing the directivity of a propagated beam of electromagnetic waves,

g Figure 9 indicates schematically in plan view, an end-on or in line arrangement of units for increasing the directivity of a beam of waves,

Figures 10 and 10a indicate diamond shaped arrangements units for obtaining unidirectional propagation,

Figure 11 illustrates a preferred form of the invention for concentrating a unidirectional beam of energy horizontally and vertically, when the length of wires is of the order of 8 to 12 wave lengths, and,

St. g ~~Figure 12 is a graph showing the proper relationship, according to the present invention, between the length of a single conductor of a pair of conductors and the angle to be given it relative to a desired direction of propagation.~~

~~In general~~, as shown in figure 1a, about a wire 2 ~~long~~, relative to the working wave length, there are two principal hollow cones 4, 6 of radiation. The cones are symmetrical about the wire 2, and the axis of the cones coincides with that of the radiator 2. ~~For a given wire, at a given wave length,~~ for a given length of wire measured in wavelengths the angle alpha α between the axes Y-Y, of each lobe or ear of the cone which appears as such in cross section, and the wire 2 is constant.

More specifically, a cross section of the solid polar diagram of ~~a wire~~ wire antenna, a number of wave lengths long and has ~~having~~ standing waves thereon, contains as many ears per quadrant as there are wave lengths in the wire. Thus, as shown in figure 1b, for a wire five wave lengths long, there are five ears in each quadrant ~~there are five ears in each quadrant~~, the principal lobes of radiation occurring along the axes Y'-Y. As indicated, the instantaneous directions of the field represented ~~alternately reverse~~ by adjacent ears are reversed. ~~by each ear is reversed.~~

Now, if it is desired to radiate energy principally in the direction of axis X-X ~~of figure 2~~ figures 2a, 2b, and 2c, the conductors, shown in figure 1, should be turned an angle alpha α relative to the direction X-X; and, in order to increase still further the directional characteristic along the axis X'-X, according to the present invention, two wires are used, each of which make an angle alpha α with the axis X'-X on opposite sides of the axis in a fashion such that the axis and the pair of wires lie in a single plane. In directions other than along the axis X-X, ~~radiation cancellation will occur mainly as a result of which, a pair of wires disposed at the angle α with respect to the X-X axis will have a radiation characteristic in the plane of the pair of wires such as shown in figure 3.~~

Insert J

Insert J3

Insert J4

By considering a long wire the equivalent of a very la
number of very short, (Herts) oscillators and by adding up the
field components at any point P having a direction angle θ
relative to the axis of the wire where the point P is a great
distance from the wire as compared to the length of the wire
such that all lines from point P to any point on the wire are
essentially parallel, it can be shown that the field strength
is given by the following proportionality for a conductor an od
number of half wave lengths long:

$$H \propto \frac{\cos\left(n \frac{\pi}{2} \cos\theta\right)}{\sin\theta}$$

The letter "n" indicates the number of half wave lengths contained in the wire.

For a wire an even number of half wave lengths long, i
similar fashion, the field strength "H" is given by the follow
proportionality:

$$H \propto \frac{\sin\left(n \frac{\pi}{2} \cos\theta\right)}{\sin\theta}$$

Where n as above indicates the number of half wave lengths on
the wire.

The value for which the angle θ in either of the above
equations makes the expression a maximum value gives ~~, of course~~
the value for the angle α ~~the wire~~ should so disposed at relat
to the direction X-X of desired wave propagation. ~~The obtain~~
of the critical value of θ for either of the above equations
~~graphically be readily~~ determined; its value for wires up to
fourteen wave lengths long is given graphically in figure 12.
practical purposes the empirical formula

$$\alpha = 50.0 \left(\frac{\ell}{\lambda}\right)^{-0.512} \text{ degrees}$$

where l equals the length of the wire and λ the wave length, both in the same units of measurement, ~~is sufficiently accurate. Where a pair of wires are used in accordance with the present invention,~~ they should be spaced apart at an angle substantially equal to twice the angle α as determined in any of the ways described above.

Insert g5

In order to obtain a bidirectional unit having a characteristic such as shown in figure 3, as already indicated, any of the arrangements shown in figures 2a, 2b, or 2c ~~figure 2~~ may be utilized. The fundamental unit is shown in figure 2a where a transmission line 10 supplies high frequency energy to a pair of wires A,B forming the angle 2 alpha with each other. The angle alpha is the angle made by one of the conductors with the X-X axis along which it is desired that the radiators A,B, propagate energy. The conductors A,B, are joined together at their apex which falls in the axis X-X as shown. The wires may be fed intermediate their ends in a fashion similar to that in which a half wave length oscillator is fed intermediate its ends. If desired, ~~of course,~~ as shown in figure ~~2b, the transmission line 10 may terminate the extremities of linear radiators A,B, rather than connect them together.~~

Insert g6

The arrangement shown in figure 2a is, ~~however,~~ preferred, ~~because~~ since it facilitates ~~allows of~~ tuning of the antenna unit comprising the pair of wires A,B. The transmission line 10 feeds energy to a U-shaped loop 12, the legs of which are short circuited by an adjustable short circuiting strap 14, representing a voltage nodal point. The ends 16 of the loop 12 supply energy derived from line 10 ~~in phase opposition~~ to ~~the conductors A,B.~~ ~~Adjustment of impedance such that there is no reflection along transmission line 10 is accomplished along the legs of the loop by suitable adjustable tapping points 18.~~

Insert g7

Use of the loop allows of completion of the tuning of the antenna wires by making the total effective tuning length of each wire of the "V" or radiating unit equal to an odd number of quarter wave lengths. The effective radiating length is the length of wire included in the "V" only, since the loop is non-radiating and can be made of any length.

When tuning of the "V" is properly accomplished by the U-loop, the system presents a pure resistive load to the transmission line. By tapping the line to the legs of the U at a suitable distance from the short circuiting strip, the effective resistance of the antenna system can be made equal to the surge impedance of the line, which is a necessary condition for maximum transmission efficiency.

It should be mentioned here that energy to the radiators A, B should always be fed thereto out of phase for otherwise at a distant point P along the axis X-X there would be radiation cancellation; and, it is to be understood that the unit so far described is not only useful for radiation purposes but may be utilized equally as well for reception. That is, the antenna system according to the present invention is equally well suited for any type of radiant action whether it be collection of radiation energy or the transmission thereof.

It is to be further ~~Moreover, it should be clearly~~ understood that the wires of each unit can be of any desired length ~~length whatsoever~~ provided they are placed at the correct angle for their particular length. For best tuning, the total over-all length of both of the wires and the "U" loop terminating them should be effectively an integral number of half wave lengths, but although the portion forming the radiation element can be of any length. The law giving the correct angle for lengths between odd and even number of half wave lengths is not given, however due to its complexity, but the empirical formula and the curve of figure 12 will be found accurate for all practical purposes, whether or not ~~where~~ the length of wire dealt with corresponds to an integral ~~does not correspond to a whole~~ number of half wave lengths.

In order to prevent undesired high angle radiation, and in order to concentrate the desired beam in elevation, the scheme shown in figure 4 may be utilized. ~~Here,~~ In figure 4, pairs of wires A,B and A', B' are placed in parallel horizontal planes and supported by masts 20 and suitably insulated therefrom by suitable insulators 22. Both pairs of wires or units are fed cophasally from a transmission line 24 through conductors 26, the wires of each pair or unit being fed in opposite phase. In order to increase the elevational concentration of radiated energy, the pair A,B and ~~the pair of wires A' and B' are placed apart in horizontal planes~~ by a substantial spacing of preferably not less than one half wave ~~by any convenient spacing and preferably at least, one-half wave~~ length ~~apart~~. The lower pair should be at least one-half wave length above ground. Bidirectional propagation ensues along the axis X'-X but in a much more concentrated form relative to the use of a single unit.

The vertical spacing of the units one above the other need not to made an integral number of half wave lengths. In addition, it should be noted that for wires several wave lengths long, vertical radiation is either zero or practically very small. ~~Specifically, it is zero for wires whose lengths are equal to an even number of half wave lengths, and small for wires an odd number of half wave lengths long. For wires whose length~~ For wires whose lengths approach ~~approaches~~ the order of magnitude from 6 to 10 wave lengths, a spacing greater than one-half wave length is preferred.

In practice, where the height of the antenna is limited by economic considerations and wherein it is desired to make ground absorption as low as possible, a good compromise is a half wave length spacing. For transmission of energy having a wave length of 17 or 18 meters, a good practical antenna may be had wherein the lower wires are about three-quarters of a wave length above ground, and the spacing between wires is one-half wave length. Eighty feet poles or masts may be used to support the wires.

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In order to obtain a unidirectional radiation characteristic, pairs of units such as shown in figure 2 may be spaced parallel and apart a distance along the axis X-X or the bisector of the angle formed by each pair of wires in each unit a distance equal to an odd number of quarter wave lengths.

Sub 46

Such a system combined with means for concentrating the beam in a direction traversing the plane of the wires of each unit is shown in figure 5. That is, figure 5 illustrates a system such as shown in figure 4 duplicated in a direction along the X'-X axis whereby, in a horizontal plane, a directional characteristic is obtained such as that shown in figure 6 and, in a vertical plane a power distribution characteristic such as shown in figure 7.

The system of figure 5, comprising the pair of wires A,B paralleled by similar pairs a, b spaced apart along the direction X'-X an odd number of quarter wave lengths and, as shown nine-quarters of a wave length behind the apex 23 of wires A,B, is excited so that the wires a, b, have standing current waves thereon 90 degrees ahead in phase of the standing current waves on wires A,B. Consequently, energy will be propagated principally along the axis X'-X towards the diverging ends of the radiators. In order to concentrate the beam of energy so radiated, similar pairs of radiators are placed below the pairs A,B and a, b in planes suitably spaced from the first mentioned pairs of radiators to obtain the desired vertical or elevational concentration. The lower pairs of radiators are excited cophasally with relative to the upper pairs through conductors 26, 26' fed by transmission line 24. In order to tune the various units there are provided U-shaped loops 30, 30' which are ~~are pro-vided~~ short circuited by straps at 32, 32', similar to ... of figure 2 and as shown in figure 11 ~~32, 32'~~.

~~Of course,~~ By exciting wires a, b 90 degrees lagging relative to radiators A, B, unidirectional propagation may be obtained in an opposite direction, or, towards the converging ends or apices of the units.

If greater concentration of the radiated energy is desired, several systems such as shown in figure 5, for example, comprising an effective radiating unit A, B and an effective reflecting unit a, b may be placed in [illegible] with other units and the several units ~~sidebyside and~~ excited cophasally. Thus, in figure 8 each of the radiating units A, B shown in plan view is provided with a reflecting unit a, b. ~~Through~~ By means of branched transmission lines as shown diagrammatically at T each system is fed cophasally as a result of which an extremely concentrated beam of energy in the plane of the units is transmitted in a direction from the reflecting units towards the radiating units or ~~the~~ reverse, depending upon the relative phase of the standing waves on the units.

The units may be arranged in end-on fashion or coaxially as shown in figure 9 where each of the units U is spaced apart in the direction of desired propagation. By making the phase difference between each of the units equal to $\left(2\pi \frac{S}{\lambda}\right)$ (where S is a spacing of each unit measured along the axis, concentrated unidirectional propagation may be obtained in either direction along the X-X axis depending upon whether or not the standing waves on the succeeding units lag or lead each other by the phase difference given according to the foregoing expression.

Other combinations will readily suggest themselves to those skilled in the art, for example, the units U may be placed diamond shaped fashion such as shown in figure 10, or, they may be superimposed as shown in figure 10a, the wires of each unit traversing each other.

dCO

In order to obtain greater concentration of the radiated beam of energy in a direction traversing the plane of each unit, the systems may be extended in the fashion shown in figure 11. Here, the system of figure 5 has been duplicated in a vertical direction, giving increased concentration of the beam in elevation. Energy is fed to the system through an impedance matching device 40 and thence cophasally to the reflecting units through a suitable connection 42. Energy is similarly fed to the radiating units through a suitable connection 44. By suitable tuning and by suitable spacing of the radiating pairs of wires and reflecting pairs of wires, unidirectional propagation may be obtained in either direction along the bisector of the angle formed by the wires of each pair.

The spacing of the antenna and reflector, of the system shown in figure 11 where the wires are 6 to 12 wave lengths long, is made preferably nine-quarters of a wave length. For wires longer than ten wave lengths, the preferred form ~~should have a~~ greater spacing between the antenna and reflector such as two and three-quarters or three and one-quarter wave lengths. For wires on the order of three or four wave lengths long, the reflector spacing from the antenna ~~should~~ be one and one-quarter wave lengths or less. In general, ~~for maximum concentration,~~ as the length of wires in terms of wave lengths increases, the reflector and antenna spacing should be increased.

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In each of the systems, ~~of course,~~ for reception, the transmission line would simply be coupled to a suitable receiver, the antenna being directed upon a transmitting station. The wires, though preferably placed in horizontal planes may be placed at any desired angle without departing from the scope of this invention. And, during transmission it may often be found desirable to have the plane of the wires tilted away from the earth and towards the direction in which the beam of energy is to be propagated.

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Having thus described my invention, what I claim is:

said conductors being angularly disposed with respect to each other, means for producing

1. A directional antenna comprising a pair of angularly disposed linear conductors, each substantially a plurality of half wave lengths long and having standing waves thereon whereby radiant action of the antenna is predominantly along the direction of the bisector of the angle formed by the conductors.

said conductors being angularly disposed with respect to each other

2. A directional transmitting antenna comprising a pair of angularly disposed linear conductors, each substantially a plurality of half wave lengths long and open-ended, and, means for exciting the radiators in phase opposition whereby standing waves of opposite instantaneous polarity are formed on the radiators.

means for producing

3. A directional antenna comprising a pair of angularly disposed linear conductors disposed in a horizontal plane, each substantially a plurality of half wave lengths long and having standing waves thereon whereby radiant action of the antenna is predominantly along the direction of the bisector of the angle formed by the conductors.

said conductors being angularly disposed with respect to each other

4. A directional transmitting antenna comprising a pair of angularly disposed linear conductors, each substantially a plurality of half wave lengths long open-ended and disposed in a horizontal plane, and, means for exciting the radiators in phase opposition whereby standing waves of opposite instantaneous polarity are formed on the radiators.

said conductors being angularly disposed with respect to each other

5. A directional antenna comprising a pair of angularly disposed linear conductors, each substantially a plurality of half wave lengths long ~~and having standing waves~~ thereon whereby radiant action of the antenna is predominantly along the direction of the bisector of the angle formed by the conductors, and another pair of conductors parallel and similar to said first mentioned pair of conductors and spaced therefrom an odd number of quarter wave lengths measured in a direction along the bisector of the angle of the conductors.

1 a. A directional transmitting antenna comprising a pair of angularly disposed linear conductors, each substantially a plurality of half wave lengths long and open-ended; means for exciting the radiators in phase opposition whereby standing waves of opposite instantaneous polarity are formed on the radiators; and, another pair of conductors similar and parallel to said first mentioned pair of conductors and spaced therefrom in a direction along the bisector of the angle of the conductors, an odd number of quarter wave lengths.

(handwritten insertions: "of conductors being angularly disposed with respect to each other"; "of a length including")

9 a. A directional antenna comprising a pair of angularly disposed linear conductors disposed in a horizontal plane, each substantially a plurality of half wave lengths long, and having standing waves thereon whereby radiant action of the antenna is predominantly along the direction of the bisector of the angle formed by the conductors, and, another pair of conductors similar and parallel to said first mentioned pair of conductors and spaced therefrom in a direction along the bisector of the angle of the conductors by an odd number of quarter wave lengths.

(handwritten insertions: "of a length including"; "means for producing")

4 a. A directional transmitting antenna comprising a pair of angularly disposed linear conductors, each substantially a plurality of half wave lengths long and open-ended and disposed in a horizontal plane; means for exciting the radiators in phase opposition whereby standing waves of opposite instantaneous polarity are formed on the radiators; and, another pair of conductors similar and parallel to said first mentioned pair of conductors and spaced therefrom in a direction along the bisector of the angle of the conductors by an odd number of quarter wave lengths.

(handwritten insertions: "of conductors being angularly disposed with respect to each other"; "of a length including")

5 ~~14.~~ A directional antenna comprising a pair of angularly disposed linear conductors, said conductors being angularly disposed with respect to each other ~~each substantially~~ a plurality of half wave lengths ~~long~~ of a length including ~~and having~~ means for producing standing waves thereon whereby radiant action of the antenna is predominantly along the direction of the bisector of the angle formed by the conductors, and, another pair of conductors similar to said first mentioned pair of conductors spaced apart from said first mentioned pair in a direction traversing the planes of each pair.

6 ~~15.~~ A directional antenna comprising a pair of angularly disposed linear ~~conductors~~, said conductors being angularly disposed with respect to each other ~~each substantially~~ a plurality of half wave lengths ~~long, and having~~ of a length including means for producing standing waves thereon whereby radiant action of the antenna is predominantly along the direction of the bisector of the angle formed by the conductors; and, another pair of conductors similar to said first mentioned pair of conductors spaced apart from said first mentioned pair, in a direction perpendicular to the planes of the pairs of conductors a number of half wave lengths.

7 ~~16.~~ An antenna comprising parallel pairs of angularly disposed conductors, said conductors being angularly disposed with respect to each other, spaced apart along the direction of the bisector of the angle formed by the conductors an odd number of quarter wave lengths, and, similar pairs of conductors in planes parallel to and spaced apart vertically from the planes of the first mentioned pairs of conductors.

8 ~~17.~~ A transmitting antenna system comprising parallel pairs of angularly disposed conductors, said conductors being angularly disposed with respect to each other, arranged in a horizontal plane having their apices spaced apart along the direction of the bisector of the angle formed by the conductors an odd number of quarter wave lengths, and similar pairs of conductors disposed in a parallel horizontal plane a vertical distance away from said first mentioned plane, equal to one or more half wave lengths.

said conductors being angularly disposed with respect to each other

Pull 13. An antenna comprising a pair of linear conductors, each substantially an odd number of half wave lengths long and angularly disposed with respect to each other at an angle equal to twice the angle for which the expression $\frac{\cos\left(n\frac{\pi}{2}\cos\theta\right)}{\sin\theta}$ is a maximum, n being the number of half wave lengths contained in each conductor.

Sub 13 14. An antenna comprising a pair of linear conductors each substantially an even number of half wave lengths long and disposed with respect to each other at an angle substantially equal to twice the angle for which the expression $\frac{\sin\left(n\frac{\pi}{2}\cos\theta\right)}{\sin\theta}$ is a maximum, where n is the number of half wave lengths in each conductor.

Insert A 11 ~~15.~~ An antenna comprising a pair of linear conductors, each substantially an odd number of half wave lengths long and angularly disposed with respect to each other at an angle equal to twice the angle for which the expression $\left(\frac{\cos\left(n\frac{\pi}{2}\cos\theta\right)}{\sin\theta}\right)$ is a maximum, (A) and a similar pair of conductors spaced from said first pair by an odd number of quarter wave lengths in a direction along the bisector of the angle of the conductors.

Insert A² 12 ~~16.~~ An antenna comprising a pair of linear conductors each substantially an even number of half wave lengths long and disposed with respect to each other at an angle substantially equal to twice the angle for which the expression $\left(\frac{\sin\left(n\frac{\pi}{2}\cos\theta\right)}{\sin\theta}\right)$ is a maximum, (A²) and a similar pair of conductors spaced from said first pair by an odd number of quarter wave lengths in a direction along the bisector of the angle of the conductors.

Insert A³ 13 ~~17.~~ An antenna comprising a pair of linear conductors, each substantially an odd number of half wave lengths long and angularly disposed with respect to each other at an angle equal to twice the angle for which the expression $\left(\frac{\cos\left(n\frac{\pi}{2}\cos\theta\right)}{\sin\theta}\right)$ is a maximum, (A³) and a similar parallel pair of conductors away from the first mentioned pair in a direction perpendicular to the planes of the pairs.

14 13. An antenna comprising a pair of linear conductors each substantially an even number of half wave lengths long and disposed with respect to each other at an angle substantially equal to twice the angle for which the expression $\frac{\sin(\frac{\ell}{2}\cos\theta)}{\sin\theta}$ is a maximum, and a similar pair of conductors away from the first mentioned pair in a direction perpendicular to the planes of the pairs.

15 20. An antenna comprising a pair of relatively long conductors disposed with respect to each other at an angle substantially equal to twice $50.9\,(\frac{\ell}{\lambda})^{-0.513}$ degrees,

16 20. An antenna comprising a pair of relatively long conductors disposed with respect to each other at an angle substantially equal to twice $50.9\,(\frac{\ell}{\lambda})^{-0.513}$ degrees, and, a similar parallel pair of conductors spaced an odd number of quarter wave lengths away from said first mentioned pair along the bisector of the angle of the conductors.

17 22. An antenna comprising pairs of long conductors, the conductors of each pair disposed with respect to each other at an angle substantially equal to twice $50.9\,(\frac{\ell}{\lambda})^{-0.513}$ degrees, and the pairs being placed in parallel planes substantially an odd number of half wave lengths apart.

18 23. An antenna comprising pairs of relatively long conductors the conductors of each pair being disposed with respect to each other at an angle substantially equal to twice $50.9\,(\frac{\ell}{\lambda})^{-0.513}$ degrees the apices of each pair being separated along the direction of the bisector of the angle formed by the conductors by an odd number of quarter wave lengths; and, similar pairs of conductors in a substantially parallel plane spaced apart from said first pairs, ℓ being the length of each wire and λ being the operating wave length in like units.

Insert B

Chs 19 to 30

Philip Shute Carter

HT:AJ

AFFIDAVIT

STATE OF New York }
COUNTY OF Suffolk } SS:

PHILIP STAATS CARTER the above named petitioner, being duly sworn, deposes and says that he is a citizen of the United States and resident of Port Jefferson in the County of Suffolk, State of New York and that he verily believes himself to be the original, first, and sole inventor of the improvements in ANTENNAE

described and claimed in the annexed specifications; that he does not know and does not believe that the same were ever known or used before his invention or discovery thereof; or patented or described in any printed publication in any country before his invention or discovery thereof or more than two years prior to this application; or patented in any country foreign to the United States on an application filed by himself or his legal representatives or assigns more than twelve months prior to this application; or in public use or on sale in the United States for more than two years prior to this application; and that no application for patent on said improvements has been filed by him or his representatives or assigns in any country foreign to the United States.

Philip Staats Carter

Sworn to and subscribed before me this day of June 5, 1930

Ludwig A. Rattermann
Notary Public

LUDWIG A. RATTERMANN
NOTARY PUBLIC
Suffolk County
Commission Expires March 30th, 1931

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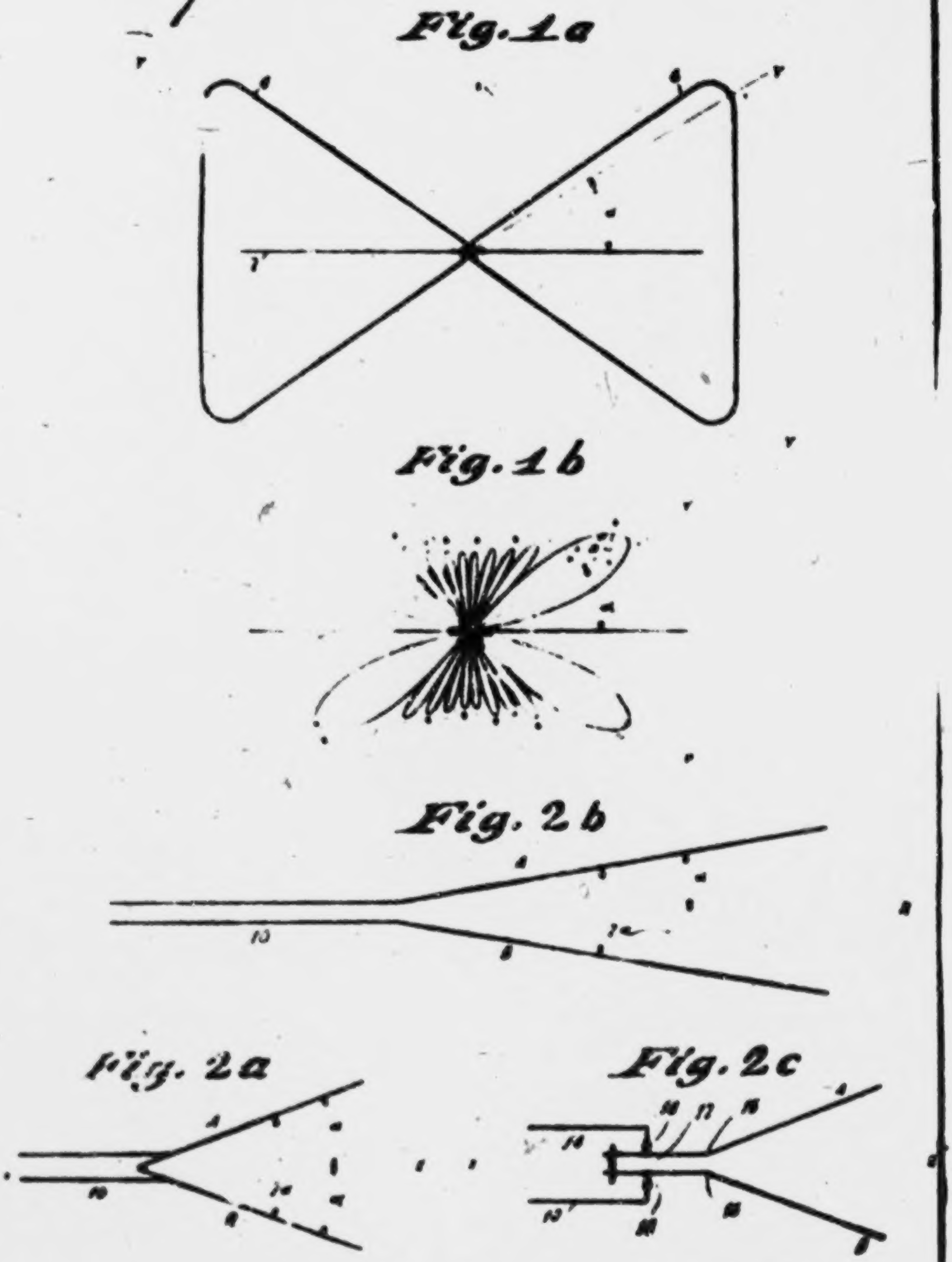

INVENTOR
P.S. CARTER
BY
ATTORNEY

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Fig. 3

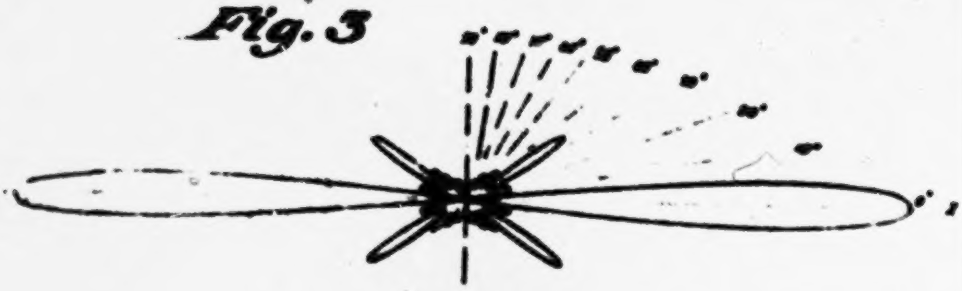


Fig. 4

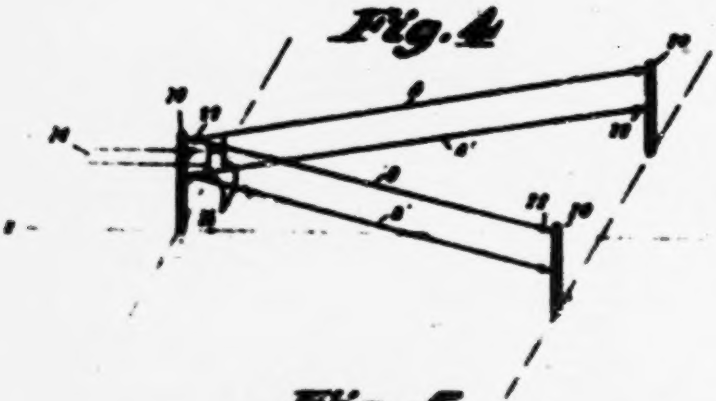


Fig. 5

Fig. 7

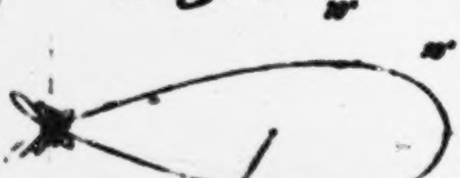
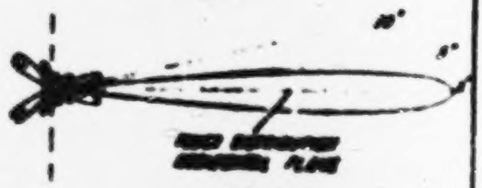


Fig. 6



INVENTOR
P. S. CARTER
BY
ATTORNEY

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Fig. 8

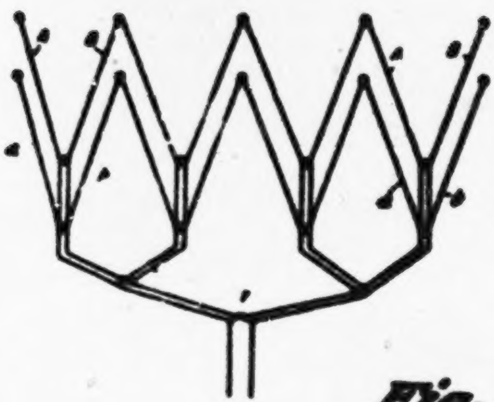
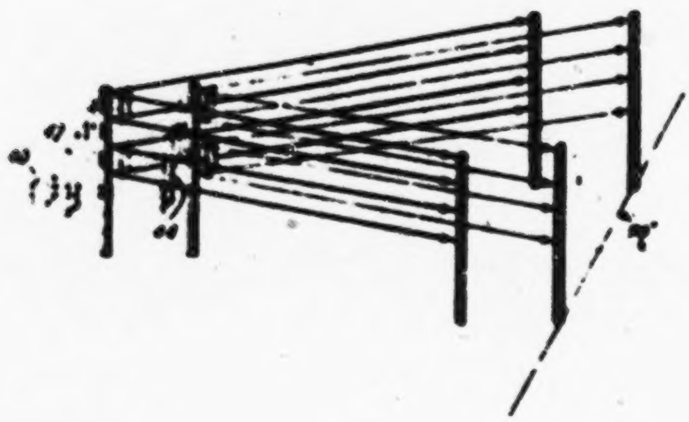


Fig. 10

Fig. 10a

Fig. 9

Fig. 11



INVENTOR
P. S. CARTER
BY

ATTORNEY

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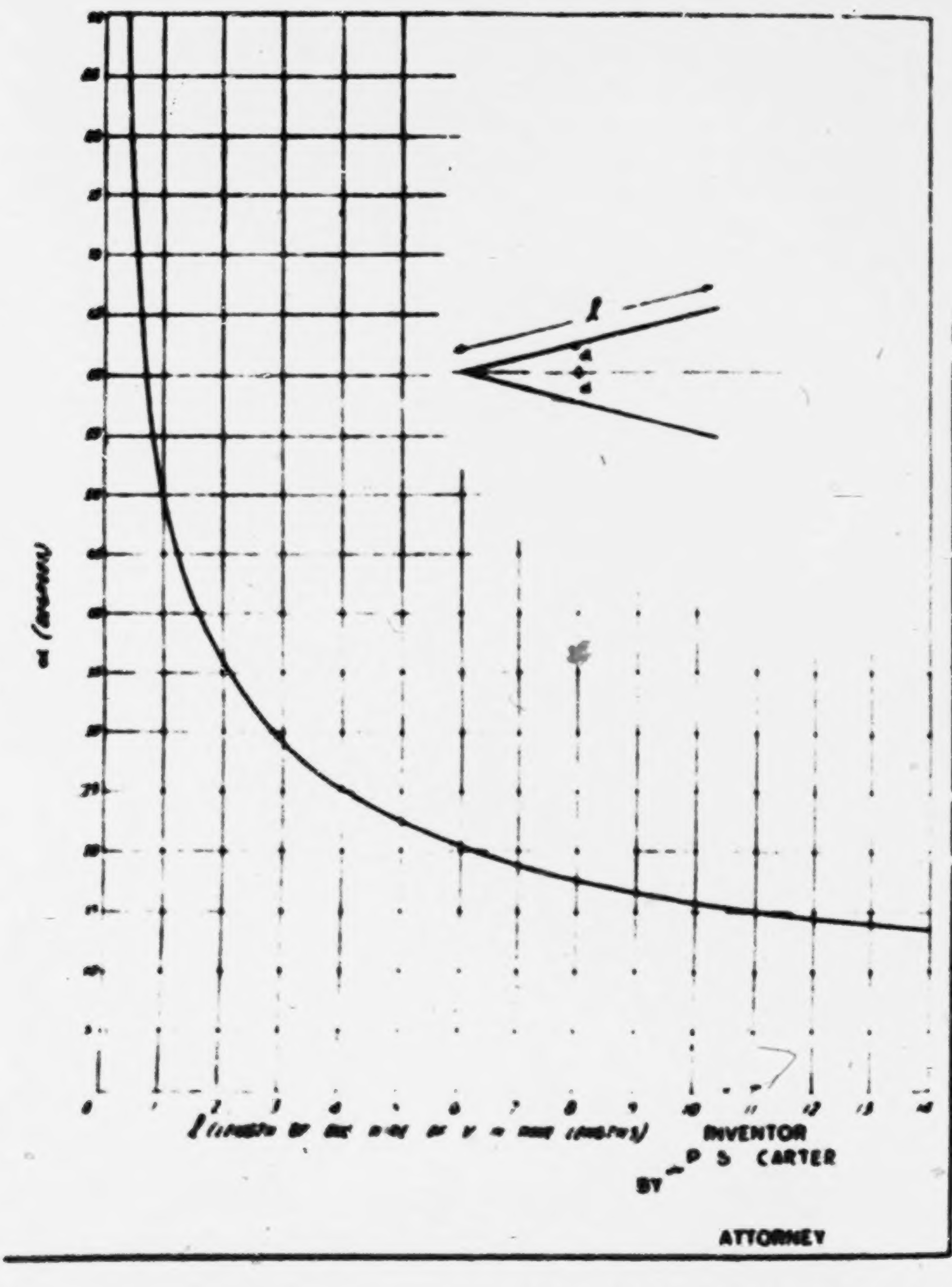
Fig. 12



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Div. 51 Form 240-[illegible] Paper No. 2

DEPARTMENT OF COMMERCE
UNITED STATES PATENT OFFICE
WASHINGTON March 3, 1931.

Please find below a communication from the EXAMINER in charge of this application.

Thomas E. Robertson

Applicant: P. S. Carter
Ser. No. 460,467
Filed June 11, 1930
For Antennae

H. G. Grover,
C/o Radio Corp. of America,
233 Broadway,
New York, N. Y.

This application has been examined.

Record is made of:

Marconi	760,463	May 24, 1904	250-33
Garcia	795,762	Jul. 25, 1905	250-11
Alexanderson	1,491,[illegible]	Apr. 22, 1924	250-11x
British Patent	290,447 (2 shts.)	Feb. [illegible], 1929	250-33
British Patent	306,693 (5 shts. - sht. 2)	Jan. 21, 1929	250-11

All the claims are rejected as incomplete since, "angularly disposed" does not sufficiently define the structure. These claims should recite with respect to what the conductors are angularly disposed.

Claims 1-3, 5, 7, 9 and 10 are further rejected as functional since they recite functions not supported by the structure recited in the claims. The limitation, "having standing waves thereon" is not a proper limitation since it recites merely a condition of the apparatus in operation and no structural feature of the system.

Claims 1, 2 and 3 are rejected as reading directly on Garcia in every structural detail. The British patents also show antennae systems having a pair of angularly disposed conductors, as in Fig. 4, of British patent 290,447, the conductors 42 are angularly disposed with respect to the horizontal.

In claims 12-22, inclusive, the definitions of the symbols used in the mathematical expressions should be included in the claims, in order to distinctly point out the invention.

R

C. D. Backus
Examiner

MAIL DIVISION
APR 23 31
U.S. PATENT OFFICE

UNITED STATES PATENT OFFICE

APPLICATION OF: P. S. Carter	:
FOR: Antennae	:
SERIAL NO. 460,4?7 FILED: June 11, 1930	:
DIVISION: 51 ROOM: 240-Annex	:

New York, N. Y.
April 22, 1931

The Commissioner of Patents

Washington, D. C.

Sir:

On and after April 24, 1931 please address all communications intended for the attorney of record of the above entitled case to

Harry G. Grover
c/o Radio Corporation of America
570 Lexington Avenue
New York City, N. Y.

Respectfully,

~~P. S. CARTER.~~
H. G. Grover

by ______________________
Attorney

1056

126

PAPER N 4
AMENDMENT A

SEP - 2 31

IN THE UNITED STATES PATENT OFFICE

- -

APPLICATION OF: PHILIP S. CARTER :

FOR: ANTENNAE :

SERIAL NO: 4[illegible]0,467 FILED: JUNE 11, 1930 :

DIVISION: 51 ROOM: 240-ANNEX :

LAST OFFICE ACTION: MARCH [illegible], 1931 :

- -

SEP 4 - 1931

New York, N. Y. August 28, 1931.

COMMISSIONER OF PATENTS,

WASHINGTON, D.C.

SIR:

In response to the Office Action of March 3, 1931, kindly amend this case as follows:

Page 11, line 13, change "Z" to the numeral 2.

Claim 1, line 2, after "conductors" and before the comma insert said conductors being angularly disposed with respect to each other.

Line 3, after "long" insert at the operating frequency.

Same line, cancel "having" and insert in place thereof means for producing.

Claim 2, line 2, after "conductors" insert said conductors being angularly disposed with respect to each other.

Claim 3, line 3, change "having" to means for producing.

Claim 4, line 2, after "conductors" and before the comma insert said conductors being angularly disposed with respect to each other.

Claim 5, line 2, after "conductors" and before the comma insert said conductors being angularly disposed with respect to each other.

Claim 6, line 2, after "conductors" and before the comma insert said conductors being angularly disposed with respect to each other.

Claim 7, line 2, after "conductors" and before the comma insert said conductors being angularly disposed with respect to each other.

Claim 8, line 2, after "conductors" and before the comma insert said conductors being angularly disposed with respect to each other.

Claim 9, line 2, after "conductors" and before the comma insert said conductors being angularly disposed with respect to each other.

Claim 10, line 2, after "conductors" and before the comma insert said conductors being angularly disposed with respect to each other.

Claim 11, line 2, after "conductors" insert , said conductors being angularly disposed with respect to each other.

Claim 12, line 2, after "conductors" insert , said conductors being angularly disposed with respect to each other.

Claim 13, line 1, after "conductors" and before the comma insert said conductors being angularly disposed with respect to each other.

Line 3, after "disposed" insert with respect to each other.

Last line, change ~~the~~ period to a comma and add n being the number of half wave lengths contained in each conductor.

Claim 14, line 3, after "disposed" insert with respect to each other.

Last line, change the period to a comma and add where n is the number of half wave lengths contained in each conductor.

Claim 15, line 3, after "disposed" insert with respect to each other.

Line 4, after "maximum," insert n being the number of half wave lengths contained in each conductor.

Same line after "and" insert a comma.

Amd a¹

Claim 16, line 3, after "disposed" insert with respect to each other.

Line 4, after "maximum," insert n being the number of half wave lengths contained in each conductor.

Amd a²

Claim 17, line 3, after "disposed" insert with respect to each other.

Line 4, after "maximum," insert n being the number of half wave lengths contained in each conductor.

Amd a³

Claim 18, line 3, after "disposed" insert with respect to each other.

Line 4, after "maximum," insert n being the number of half wave lengths contained in each conductor.

Amd a⁴

Claim 19, line 2, after "disposed" insert with respect to each other.

Last line, change the period to a comma and add l being the length of the wire and λ the operating wave length in like units.

Amd a⁵

Claim 20, line 2, after "disposed" insert with respect to each other.

Last line, change the period to a comma and add l being the length of each wire and λ being the operating wave length in like units.

Amd a⁶

Claim 21, line 2, after "disposed" insert with respect to each other.

Last line, change the period to a comma and add l being the length of each wire and λ being the operating wave length in like units.

Amd a⁷

Claim 22, line 2, after "disposed" insert with respect to each other.

46

Last line change the period to a comma and add l being the length of ... wire and λ being the operating wave length in like ...

94

REMARKS:

Each of the claims have now been amended to state with particularity that the conductors are angularly disposed with respect to each other, and hence the rejection of incompleteness should be withdrawn.

It is respectfully submitted that claims 1, 2, 3, 5, 7, 9 and 10 are not functional. Each of claims 1, 2 and 3 call for means to produce standing waves on the radiators. The recitation of "means", of course, precludes these claims from being functional. Moreover, it is respectfully submitted that the quintessence of the present invention is the production of standing waves on the wires. Consequently, there should be no objection to this limitation in the claims inasmuch as the art clearly does not teach this feature. Similar remarks are applicable in connection with claims 7, 9 and 10 which require the parallel disposition of pairs of angularly disposed conductors whereby a beam of energy, propagated mainly in the direction of the bisector of the angle formed by the conductors, is concentrated. It is to be noted that here also these features are not to be found in the art of record and, consequently, upon reconsideration, it is thought that the formal objections to these claims should be withdrawn and the claims allowed.

It is respectfully submitted that claims 1, 2 and 3 are not anticipated by Garcia. It is to be noted that each of these claims requires conductors having a plurality of standing waves thereon; and, claim 2 in particular requires the standing waves on the conductors to be in phase opposition. In Garcia the conductors are all excited in phase as a simple inverted L type of antenna. There is no indication that a number of standing waves are produced upon each conductor of the antenna and still less does Garcia teach the fact that the waves on each conductor are to be in phase opposition.

In figures 1 and 3 of British patent 2.5,693, standing waves are not produced upon the linear conductors of the antennae systems but on the contrary, traveling waves are produced therein. Although figure 2 of the British patent requires the production of standing waves on the linear conductors, propagation is at right angles to the plane of the conductors and not as required by these claims on the bisector of the angle formed by the conductors. Similarly in figure 5 of British patent 290,447, the conductors 42 are parallel to each other and cannot be said to be angularly disposed whereby radiation occurs in the direction of the bisector of the angle formed by the conductors. Consequently, upon reconsideration, claims 1, 2 and 3 should be allowed over the British patents of record.

No art was cited against claims 13 to 22 inclusive, and, as they have been amended to include the explanation of the mathematical expressions used, should now be found allowable.

For the foregoing reasons allowance of the case in its present form is thought to be in order and is, therefore, respectfully requested.

Respectfully submitted,

PHILIP S. CARTER

BY H. G. Grover

Attorney

HT:AU

PAPER NO 5
AMENDMENT B

UNITED STATES PATENT OFFICE

APPLICATION OF: P. S. CARTER

FOR: ANTENNAE

SERIAL NO.: 460,467 FILED: JUNE 11, 1930

DIVISION: 51 ROOM: 240-ANNEX

LAST OFFICE ACTION: MARCH 3, 1931.

NOV 16 1931

New York, N. Y., November 15, 1931.

COMMISSIONER OF PATENTS,

WASHINGTON, D. C.

DEAR SIR:

Please amend the above-entitled application as follows:

Add the following claims:

B'

1. An antenna arrangement comprising a pair of diverging linear conductors angularly disposed with respect to each other, another pair of angularly disposed diverging conductors similar to said first mentioned pair and spaced apart from said first pair in a direction along the bisector of the angle of the conductors, both said pairs of angularly disposed conductors being arranged to form opposite angles of a four sided plane figure.

2. A diamond-shaped antenna arrangement comprising ~~two pairs of V-shaped antennae arranged to form a parallelogram~~.

3. An antenna system comprising a pair of linear conductors angularly disposed with respect to each other, each of a length including substantially a plurality of one-half wave lengths ~~long and~~ open-ended, another similar pair of angularly disposed linear conductors also a plurality of one-half wave lengths ~~long and~~ open-ended, both of said pairs being so arranged that the angles formed by ~~each~~ said pair face one another, and means for exciting the radiators of each pair in phase opposition whereby standing waves of opposite instantaneous polarity are formed on the radiators.

32 26. A directional transmitting antenna arrangement comprising ~~two~~ a pairs of V-shaped antennae arranged to form a parallelogram, and means for exciting the radiators of each pair in phase opposition whereby standing waves of opposite instantaneous polarity are formed on the radiators.

33 27. A directional antenna arrangement comprising two pairs of open-ended V-shaped antennae arranged in a horizontal plane such that the open ends of each pair point in opposite ~~directions with respect to the other pair~~.

28. A directional antenna ~~arrangement~~ comprising two pairs of open-ended V-shaped antennae ~~arranged~~ such that the angles formed by the individual conductors of each pair antennae face each other and the open ends of each pair point in different directions.

29. A directional antenna arrangement comprising a pair of V-shaped antennae arranged in such manner that the angles formed by the individual conductors of each pair face each other.

30. A directional antenna comprising a pair of linear conductors angularly disposed with respect to each other, each substantially a plurality of one-half wave lengths long, open-ended, and disposed in a plane at an angle from the horizontal, and means for exciting the radiators in phase opposition whereby standing waves of opposite instantaneous polarity are formed on the radiators.

26 ~~[illegible]~~. A directional antenna comprising a pair of linear conductors angularly disposed with respect to each other and

said plane extending in the desired direction of transmission, each conductor being

placed in a plane at an angle to the horizontal, ~~each substan-~~

of a length including

~~tially~~ a plurality of one-half wave lengths ~~long~~, means for producing standing waves thereon whereby radiant action of the antenna is predominantly along the direction of the bisector of the angle formed by the conductors, and another pair of conductors similar and parallel to said first mentioned pair of conductors and spaced therefrom in a direction along the bisector of the angle of the conductors by an odd number of one-quarter wave lengths.

27 ~~[illegible]~~. A directional transmitting antenna comprising a pair of linear conductors angularly disposed with respect to

of a length including

each other, each ~~substantially~~ a plurality of one-half wave

and being

lengths ~~long and~~ open-ended, and disposed in a plane at an angle

said plane extending in the desired direction of transmission

from the horizontal, means for exciting the radiators in phase opposition whereby standing waves of opposite instantaneous polarity are formed on the radiators, and another pair of conductors similar and parallel to said first mentioned pair of conductors and spaced therefrom in a direction along the bisector of the angle of the conductors by an odd number of one-quarter wave lengths.

28 ~~[illegible]~~. A directional transmitting antenna comprising a

the conductors of each pair being

plurality of ~~pairs of~~ linear conductors angularly disposed with

conductor being of a length including

respect to each other, each ~~substantially~~ a plurality of one-

being and the plane of said pairs being

half wave lengths ~~long and~~ open-ended, ~~and disposed in a~~ horizontal plane along the bisector of the angle of the conductors, means for exciting the two radiators of each pair in phase opposition whereby standing waves of opposite instantaneous polarity are formed on the radiators of each pair, and means for feeding the successive pairs of radiators so that the currents

29

in the successive radiators of each pair differ in phase by an angle $2\pi S/\lambda$ where S is the spacing along the and λ the wave length.

29 ~~28~~. A directional transmitting antenna comprising a plurality of pairs of linear conductors, the conductors of each pair being angularly disposed with respect to each other, each conductor being substantially of a length including a plurality of one-half wave lengths ~~long~~ and being open-ended, ~~and~~ said plurality of pairs being disposed in a plane said plane extending in the desired direction of transmission at an angle from the horizontal, means for exciting the two radiators of each pair in phase opposition whereby standing waves of opposite instantaneous polarity are formed on the radiators of each pair, and means for feeding the successive pairs of radiators so that the currents in the successive radiators of each pair differ in phase by an angle $2\pi S/\lambda$ where S is the spacing and λ the wave length.

30 ~~29~~. A broadside directional antenna comprising a pair of linear conductors angularly disposed with respect to each other, another pair of angularly disposed linear conductors arranged adjacent and in the same plane with said first pair so that said two pairs are side by side and have their acute angles opening in the same direction, and means for producing standing waves thereon whereby radiant action of the antenna is predominantly along the direction of the bisector of the angle formed by the conductors of each pair for effecting beam concentration.

Insert C2

REMARKS.

Thirteen new claims 23 to 35 are herein being added to the application to more adequately protect applicant's invention.

New claims 23 to 29 are directed to a diamond-shaped antenna construction such as is illustrated in either Figure 10 or Figure 10A, which particular arrangement is not to be found anywhere in the prior art so far as applicant is aware.

New claim 30 is somewhat similar in scope to claim 1 and includes a limitation not found therein.

7

New claims 31 and 32 are very similar in scope to claim 7 and read upon Figures 5, 9 and 11 of applicant's drawings.

New claims 33 and 34 are quite specific to an antenna construction wherein the successive radiators of each pair differ in phase by a particular formula.

New claim 35 is directed to the antenna construction illustrated in Figure 8 of the drawings. So far as applicant is aware this arrangement is not shown anywhere in the prior art and is thought to be clearly novel.

Since these new claims clearly distinguish from the disclosures of the references cited by the Examiner their allowance is respectfully requested.

Respectfully,

P. S. CARTER

By H. G. Grover
Attorney.

HGG:BC

31
C. N. L.

1066

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Div. 51 Room 2969 RSM:JB Paper No. 6

Address only "The Commissioner of Patents, Washington, D. C." and not any official by name

DEPARTMENT OF COMMERCE
UNITED STATES PATENT OFFICE
WASHINGTON Mar. 7, 1932.

All communications respecting this application should give the serial number, date of filing, and name of the applicant

Please find below a communication from the EXAMINER in charge of this application.

Thomas E. Robertson
Commissioner of Patents.

Applicant P.S.Carter.

H.G.Grover,
c/o Radio Corp.of America,
570 Lexington Ave.,
New York, N. Y.

Ser. No. 460,487
Filed June 11,1930
For Antennae.

MAILED
MAR 7 1932

Responsive to amendments filed September 2, 1931 and November 17, 1931.

Additional record is made of:

VonArco 1,827,064 Oct. 13, 1931 250/33.1

Claims 1, 3, 5, 7, 9 and 10 are again rejected as being functional since there is no structure to support the function of "having standing waves thereon" nor to support the statement in regard to the directional transmission. It appears that in order to support these functions it is necessary to state that the antennae are open-ended, and that means to excite them in phase opposition is provided. As pointed out in the last Office action, the limitation "having standing waves thereon" is merely a condition of the apparatus during use and not a structural limitation.

Claims 1 and 3 are further rejected as unpatentable over Gareis, of record, or VonArco, cited above, since they read substantially directly on either of these references in structure.

Claim 2 is rejected as being functional since the production of standing waves does not follow from the structure named.

Furthermore, it appears that this claim is drawn to substantially similar subject-matter as a copending application to Peterson assigned to the same assignee.

4... ..57 33

It is not clear where applicant wishes the insertion made in claim 7, line 2, since no comma follows "conductors." Applicant should make it clear where he wishes this entered.

Claims 11, 12, 21 and 22 are rejected as being incomplete since the indefinite statements in regard to the spacing of the elements do not define a complete structure. Applicant has only shown a particular spacing that will satisfy his invention and should define the structure in the claims so as to point this out.

New claims 23-32, inclusive, and claim 35 are required to be cancelled as being drawn to an invention not previously claimed. Furthermore, claims 23-29 are drawn to the combination shown in Fig. 10 and 10a, which is a different invention from that covered by the claims and accordingly not allowable in the same application. Likewise, claim 35 is drawn to a different invention shown in Fig. 8 and could not be claimed in the same application as the allowed claims even if submitted with a supplemental oath.

Claims 4, 6, 8, 13-20, 33 and 34 appear to be allowable.

RMW

C. D. Davis

Examiner.

1068

128

PAPER NO 7
AMENDMENT C'

MAIL DIVISION
AUG -8 32

UNITED STATES PATENT OFFICE

C

APPLICATION OF: P. S. CARTER
FOR: ANTENNAE
SERIAL NO.: 460,467 FILED: June 11, 1930
DIVISION: 51 ROOM: 5628
LAST OFFICE ACTION: March 7, 1932.

PATENT OFFICE
AUG 8 1932
DIV. 51 FILED

New York, N. Y., August 5, 1932.

COMMISSIONER OF PATENTS

WASHINGTON, D. C.

DEAR SIR:

In response to the Office action of March 7, 1932, please amend the above-entitled application as follows:

Claim 6, line 3, after "and" cancel "having standing waves" and substitute therefor --means for exciting the radiators in phase opposition whereby standing waves of opposite instantaneous polarity are formed--.

C'

Claim 7, line 2, before "in" cancel "disposed";

line 3, after "and" cancel "having" and substitute therefor --means for producing--.

Claims 9 and 10, line 3, change "having" to --means for producing--.

Claim 11, line 3, after "spaced" insert --apart vertically--.

Claim 12, line 3, after "apart" insert --along the direction of the bisector of the angle formed by the conductors--;

line 5, after "a" insert --vertical--.

Claim 21, line 5, after "in" insert --parallel--.

Claim 22, line 4, after "separated" insert --along the direction of the bisector of the angle formed by the conductors--;

line 6, after "plane" and before the comma insert --spaced apart from said first pairs--.

Claim 23, line 2, after "conductors" insert --, the conductors of each pair being--;

line 3, after "each" second occurrence insert --conductor being--;

line 4, cancel "and" second occurrence and substitute therefor --said plurality of pairs being--.

Claim 24, line 2, after "conductors" insert --, the conductors of each pair being--;

line 3, after "each" second occurrence insert --conductor being--;

line 4, cancel "and" second occurrence and substitute therefor --said plurality of pairs being--.

Claim 25, line 1, after "A" insert --broadside--;

last line, after "pair" and before the period insert --for effecting beam concentration--.

Add the following claim:

§ 16. A broadside directional antenna comprising a pair of linear conductors angularly disposed with respect to each other in a horizontal plane, another pair of angularly disposed linear conductors arranged adjacent and in the same plane with said pair so that said two pairs are side by side and having their apex angles pointing in the same direction said pairs being arranged to be excited in phase opposition whereby standing waves of opposite instantaneous polarity are formed thereon.

C 2/

Pap. B

add 1

REMARKS.

The rejection of claims 1, 2, 5, 5, 7, 9 and 10 as being functional is not understood inasmuch as claims 1 and 2 have previously been amended to recite "means for producing standing waves", a limitation to structure which clearly supports the statement in the claims in regard to directional transmission. Claims 5, 7, 9 and 10 have now been similarly amended to overcome the Examiner's rejection.

Apparently, the manner of producing standing waves on antennae is not clearly understood by the Examiner, otherwise he would not have made the statement that it is necessary for the antennae to be open-ended to produce standing waves. It is submitted that standing waves may be produced on antennae whether they are open-ended or even closed by a short circuit. One method of obtaining horizontal standing waves as long as the operating wave length on elevated conductors is described in Alexanderson patent 1,360,167 of November 23, 1920, to which the Examiner's attention is invited. To produce standing waves it is merely necessary that the termination of the antennae be such that the currents in the wires are reflected from the ends thereof in proper phase relation. The requirements to be followed are that the attenuation of the wires should not be so great that

36

the currents are dissipated therein before they reach the ends of the wires, and that the termination should not have a resistance equal to the surge impedance of the wires so as to cause traveling waves. In order to effect the standing wave phenomena the current and the voltage at the reflecting terminal of the line, where the wires are open-ended or short-circuited, must lead or lag with respect to one another." In view of this explanation it will be seen that applicant need not unduly limit his invention to open-ended conductors when he is clearly entitled to broad claims consistent with the state of the art omitting this unnecessary limitation. It is urged that the structure disclosed in these claims is sufficiently adequate to produce an operative device in accordance with applicant's teachings, and that the Examiner should not deny applicant a broad claim to which he is clearly entitled as a protection for his invention on the ground that because it is broad it is functional. It is requested that the amendments to these claims, which now call for "means for producing standing waves" or some such equivalent, provide sufficient structure to support any and all statements appearing thereon and render the claims clear and concise.

The rejection of claims 1 and 3 as being unpatentable over Garcia patent 798,762, July 25, 1905, or Vandree patent 1,827,064, October 13, 1931, is clearly not well taken since both of these claims are limited to "directional antennae" and to "means for producing standing waves" to effect applicant's purpose, features not shown, taught or even suggested in the disclosures of the references. Further, claims 1 and 3 call for conductors a plurality of half wave lengths long, a limitation not even mentioned in the cited art. In this connection, it should be noted that the Garcia patent was filed in 1901 at a time when wave lengths of the

conductor of one-half wave length would be equivalent to, let us say, 1000 meters or over 3000 feet, a distance more than half a mile which is a length greater than any antenna ever built for those waves. From this it will be seen that the claims additionally distinguish over the Garcia patent by the recitation of the specific length of the conductors. Further, claim 3 calls for the conductors disposed in a horizontal plane, a feature of which the VonArco patent is entirely silent. In fact, to dispose the conductors in a horizontal plane would be to proceed directly contrary to VonArco's teachings who specifically states on page 1, lines 29 to 34 of the patent that it is his intention to dispose a series of linear oscillators with varying altitude and azimuthal angles. The disclosures of both references are directed to antennae adapted to radiate uniformly in all directions and are clearly irrelevant. With all due respect to the Examiner's opinion, they cannot possibly be used as anticipations without violating their expressed teachings and without distorting and reading into the specifications of the disclosures a mode of operation of which they are entirely silent and which proceeds directly contrary to their inventions.

The reasons mentioned above in connection with claims 1, 3, 5, 7, 9 and 10 apply with equal force and effect to claim 2. The rejection of this claim is clearly inconsistent with the allowance of claim 4 which is of almost identical scope with claim 2 except for the limitation "disposed in a horizontal plane" appearing in claim 4. Either claim 2 is allowable for the same reason that claim 4 was allowed or else claim 4 should be rejected on the same ground of functionality as was claim 2. However, since the Examiner's position is clearly untenable this contention will not be pursued further as the allowance of claim 2 is believed to be clearly in order.

With reference to the statement that claim 2 is drawn to substantially similar subject matter as a copending application of Peterson assigned to the same assignee, it is submitted that applicant has diligently searched through the Peterson applications and has failed to find any disclosure of angularly disposed linear conductors, open-ended, and having means for exciting the radiators in phase opposition to obtain standing waves of opposite instantaneous polarity thereon. Since Peterson's applications are numerous, applicant's attorney will appreciate the citation of the serial number which the Examiner has in mind in order to clearly point out the distinguishing characteristics thereover.

Applicant regrets that the amendment to claim 7, line 2, appearing in his previous amendatory paper of August 28, 1931 was not clear and submits that the insertion should be made immediately after the word "conductors" appearing in the second line of this claim.

Claims 11, 12, 21 and 22 have been amended and are now thought to be definite and exact in regard to the spacing of the elements. These claims are now thought to be allowable for the same reason that claims 13 to 20 have been allowed.

Claims 33 and 34, which have been allowed, have been amended to render them more difinite. It is submitted that the scope of the claims has not been changed one iota and it is requested that these claims be permitted to remain allowed.

The rejection of claims 23 to 32 and 35 as being drawn to invention not previously claimed is not understood since applicant has at all times submitted claims generic to all species disclosed in the drawing and is clearly entitled to claims covering three of the species. It is submitted that original claims 1 to 4, 13 and 19 are generic to all species. None of the original claims heretofore presented are specific to any one particular

C6

species. For example, claims 5 to 9, 15, 16 and 20 are considered to be generic to Figures 5, 8, 9 and 11. Further, original claims 9, 15, 16 and 20 are also considered to be generic to Figures 10 and 10A. For this reason, it is firmly believed that applicant is clearly entitled to present claims to other species which he has all the time been claiming generically. If the Examiner persists in the requirement that these claims be cancelled, he is requested to point out authority for his action since it is considered to be clearly unwarranted and a departure from well established practice. An action on the merits of these claims is respectfully requested.

New claim 36 is of scope similar to claim 35 and is directed to the arrangement shown in applicant's Figure 8. This claim distinguishes over the art for the same reasons heretofore pointed out in connection with claim 35.

Claims 4, 6, 8, 15 to 20, 33 and 34 have been indicated as being allowable.

Reconsideration of all claims in their present form and their allowance, together with newly presented claim 36, are respectfully requested.

Respectfully submitted,

P. S. CARTER

By H. S. Grover
Attorney.

CHB:BC

... 7 41
C. K. D.

Div. 51 Room 5626

DEPARTMENT OF COMMERCE
UNITED STATES PATENT OFFICE
WASHINGTON December 8, 1932.

Paper No. 8

Address only "The Commissioner of Patents, Washington, D. C." and not any official by name

RR:1207

Please find below a communication from the EXAMINER in charge of this application.
Thomas E. Robertson
Commissioner of Patents.

MAILED DEC 8 1932

H. G. Grover,
C/o Radio Corp. of America,
570 Lexington Avenue,
New York, N. Y.

Applicant: P. S. Carter
Ser. No. 460,467
Filed June 11, 1930
For Antennae

Responsive to amendment filed August 6, 1932.

Claims 1 and 3 are again rejected as unpatentable over Garcia or Von Arco since they read substantially directly on these references. The sole distinction applicant points out is recited in the functional descriptive word "directional". Obviously, the transmitters in either of these patents form means for producing standing waves on the antennae.

The requirement that claims 23-32 be cancelled as being drawn to a different invention than that previously claimed is repeated. It is pointed out that no claim generic to the several species illustrated is included in the application. Claims 1-4, 13, and 19 read on a single antenna unit such as is used in all the species but they accordingly are drawn to a sub-combination and not to a generic form of the invention. Claims 5-8, 15, 16 and 20 are generic only to Figs. 8, and 9, but also read on a horizontal unit of the antennae shown in Figs. 5 and 11. Claims 9, 10, 17, 18 and 21 read specifically on Fig. 4 only but may also be a unit in the arrays of Figs. 5 and 11.

Claims 11, 12 and 22 are specific to the embodiment illustrated in Figs. 5 and 11.

460467 41 8

Claims 23-29 submitted in the amendment filed November 17, 1931 read only on Figs. 10 and 10a and are not supported by any generic claims.

Claims 33 and 34 read on Fig. 9 but also are generic to the unit used in Figs. 5 and 11.

Claims 35 and 36 read only on Fig. 8 and are supported by no generic claims.

Since no generic claim is found in the application and since applicant elected in filing the original application to prosecute claims specific to Figs. 5 and 11, claims 23-29 and claims 35 and 36 drawn to Figs. 10 and 10a and Fig. 8, respectively, are required to be cancelled.

see preceding page

Claims 30-32 are rejected as not being supported by sufficient disclosure since no illustration of the antennae inclined to the horizontal is included.

Claims 2, and 4-22 appear to be allowable.

D. D. Downing
Examiner

RM

289

1077

PAPER NO 4 2
AMENDMENT

UNITED STATES PATENT OFFICE

APPLICATION OF: P. S. CARTER

FOR: ANTENNAE

SERIAL NO.: 463,467 FILED: June 11, 1930

DIVISION: 51 ROOM: 5628

LAST OFFICE ACTION: December 8, 1932.

PATENT OFFICE
MAY 10 1933

New York, N. Y., May 6, 1933.

COMMISSIONER OF PATENTS

WASHINGTON, D. C.

DEAR SIR:

In response to the Office action of December 8, 1932, please amend the above-entitled application as follows:

Page 8, line 8, singularize "systems".

Cancel claim 1 and rewrite same as follows:

37. A directional antenna comprising a pair of linear conductors angularly disposed with respect to each other, each of said conductors being substantially a plurality of half wave lengths long at the operating frequency, and means for energizing said conductors out of phase with respect to each other whereby radiant action is predominantly along the direction of the bisector of the angle formed by the conductors.

Cancel claim 3 and rewrite same as follows:

38. A directional antenna comprising a pair of linear conductors in a horizontal plane angularly disposed with respect to each other, each substantially a plurality of half wave lengths long, and means for energizing said conductors out of phase with respect to each other whereby radiant action of the antenna is predominantly along the direction of the bisector of the angle formed by the conductors.

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1078 Claims 6, 7 and 9, line 3, after "long" insert a comma and cancel "and".

Claim 10, line 3, after "long" insert a comma and cancel "and"; last line, singularize "planes" and "pairs".

REMARKS.

The specification has been amended in order to overcome an obvious typographical error.

Claims 1 and 3 have been cancelled and rewritten as new claims 37 and 38 in order to more clearly distinguish over the Garcia and Von Arco citations. As now written these claims call for, in addition to the limitations previously pointed out, means for energizing the angularly disposed conductors out of phase with respect to each other in order to obtain the desired radiant action. The systems of the references, it should be noted, utilize conductors which are all excited in phase, just like the simple inverted "L" type of antenna. For this reason these claims are now considered to be clearly allowable, early notice of which is respectfully requested.

Claims 6, 7, 9 and 10, which have been indicated as being allowable, have been amended merely in the interest of clarity. Since the scope of these claims has not been changed one iota no objection should be made to these minor changes and for this reason it is requested that they remain allowed.

Claims 2 and 4 to 22 inclusive stand allowed.

Claims 23 and 24 have previously been allowed in the Office action dated March 7, 1932, and since no objection has been raised by the Examiner in his last Office action it is assumed that these claims are also allowable.

The requirement that claims 25 to 29 be cancelled on the ground that there is no generic claim in the application is considered to be ill founded and its reconsideration is respectfully requested. It is submitted that claims 9, 15 and 16 are generic in this application not only to Figures 5 and 11, but

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also to figures 10 and 10A. More specifically, these claims recite that there are two similar pairs of conductors spaced apart from each other in a direction along the bisector of the angle. These claims were specially drafted and worded in this particular manner in order to generically cover the specific arrangements of Figures 10 and 10A and for this reason applicant is clearly entitled at this time to draft other claims which are limited to these last two figures. It is respectfully advised that the Examiner should not be misled by the mere term "similar" which, in its ordinary dictionary meaning, expresses the idea of bearing a resemblance to something else, but not being completely identical. (Note Funk & Wagnalls dictionary) Apparently the Examiner has taken this expression "similar" to mean that the pairs of wires must be parallel to each other. This is not so since applicant has specifically drafted claims employing the term "parallel" wherever he has meant to designate parallel pairs of wires. In view of the foregoing, it is thought that the Examiner will readily see that he was in error in his interpretation of these claims and that he will withdraw his objection to claims 23 to 29, an action on the merits of which is respectfully requested.

As regards claims 30 to 32, which are limited to an antenna inclined to the horizontal, it is not agreed that these claims are not supported by the disclosure of the specification inasmuch as the last paragraph on page 12 adequately describes such an arrangement. Moreover, the drawings adequately illustrate an antenna in a plane which may be considered either to be horizontal or at an angle inclined to the horizon. It should be noted that the drawings do not show any horizontal reference and for this reason they are illustrative of all antennas which have their planes either horizontal or at an angle inclined to the horizon. In this connection applicant submits that the

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rejection of these claims is extremely technical since the invention is adequately described and illustrated and it would not aid in explaining the invention further to illustrate antennae both horizontal and at an angle with respect to the horizon. It is noted that claim 34 which stands allowed is similarly limited to antennae at an angle to the horizon. For these reasons it is thought that the Examiner will readily appreciate applicant's position and will withdraw his rejection of these claims.

The Examiner's contention that claims 35 and 36 read only on Figure 8, it is respectfully submitted, is considered to be ill founded since claims 1 to 4, 13 and 14 are believed to be generic to all of the claims and not to be of the sub-combination type as considered by the Examiner. In fact, all claims other than those immediately mentioned above are sub-combination claims since they are specific to one or more figures, whereas claims 1 to 4, 13 and 19 are generic to all figures.

In view of the foregoing, it is thought that all claims now present in this application are allowable and, therefore, allowance is earnestly requested so that this application may soon pass for issue.

Respectfully submitted,

P. S. CARTER

By H G Grover

Attorney.

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July 28, 1933.

P. S. Carter,
No. 460,467.

Examiner, Division 51:

The requirement of division in this case was restated in the office letter of December 8, 1932. It was held there that Claims 1-4, 13, 19, read on a single antenna unit. This is correct but they are not limited to a single antenna unit. The words of these claims include "comprising" and are directed to an antenna "comprising," which word is not an exclusive word. Claims 2, 4, 13, 19, read it is thought upon all the figures in the case, viz., Figures 2, 4, 5, 11, 8, 9, 10. Similarly it must be held that the form which reads upon Figure 4 also reads upon Figures 5 and 11, and since Figure 8 is described as being made of units similar to Figure 5 those claims which read on Figure 5 also read upon Figure 8.

There are certain claims, as 23-29, which are limited to Figure 10. Other claims, as 35, 36, are limited to the broadside arrangement of Figure 8. These constitute distinct species and election between them is necessary if no generic

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claims are found which cover them.

Analysis of the claims indicates that Claims 2, 4, 13, 14, 19, 30, 37, 38, read upon Figures 2, 4, 5, 11, 8, 9, 10, and are generic; that Claims 3-8, 15, 16, 20, 31, 32, 33, read on Figures 5, 11, 8, 9; that Claims 9, 10, 17, 18, 21, read upon Figures 4, 5, 8, 11; that Claims 11, 12, 22, read upon Figures 5, 8, 11; that Claim 34 reads on all figures except Figure 2.

Election between Claims 23-29, upon the one hand, and Claims 35, 36, upon the other, is approved if none of the claims 2, 4, 13, 14, 19, 30, 37, 38, which are generic to these two forms, are found allowable. Otherwise election does not appear to be necessary, nor if applicant has generic claims is it thought that he should be required to cancel the claims reading upon Figure 10.

There is another line in the case between the words "horizontal", Claims 4, 8, 12, 33, 36, 38, and "inclined to the horizontal," in Claims 30, 31, 32, 34. If the generic claims are found allowable, this distinction would constitute a third species, otherwise election should be made in this instance also.

The examiner has rejected the claims "inclined" as comprising new matter and the paragraph above need be taken into consideration only if that rejection is withdrawn.

CHP:MS Examiner of Classification.

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Div. 51 Room 5460 Paper No. 19

Address only "The Commissioner of Patents, Washington, D. C." and not any official by name

DEPARTMENT OF COMMERCE
UNITED STATES PATENT OFFICE
WASHINGTON

August 8, 1933.

Please find below a communication from the EXAMINER in charge of this application.

Thomas E. Robertson
Commissioner of Patents

Applicant: P. S. Carter
Ser. No. 460,467
Filed June 11, 1930
For Antennae

H. G. Grover,
c/o Radio Corp. of America,
570 Lexington Avenue,
New York, N. Y.

MAILED
AUG 8 1933

Responsive to amendment filed May 9, 1933.

It is noted that claims 2, 4, 13, 14, 19, 37 and 38 are drawn to substantially the same invention as is covered by the claims of an allowed application of Lindenblad assigned to the same assignee. Accordingly, these claims are rejected on the ground of double patenting. Claims 13, 14 and 19 give specific angles of separation, all of which are merely variations within the scope of claims allowed in the above-mentioned application and are not considered patentably distinct therefrom.

Claims 30, 31, 33 and 34 are not properly illustrated since no showing in the drawing of the conductors arranged at an angle to the horizontal is made. Since this feature is claimed particularly it must be illustrated.

The examiner of classification held in substance that claims 2, 4, 13, 14, 19, 30, 37 and 38 are generic and if none of these claims are found allowable election between 22-29 and, 30 and 36 is approved.

Accordingly, since no generic claim is found allowable the requirement of election of species is held

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in abeyance pending presentation of an allowable generic claim. No action on the merits of claims [illegible], [illegible] and 34 is made at this time since applicant has made no election of species.

Claims [illegible]-12, 1[illegible]-1[illegible], [illegible] and [illegible] appear to be allowable.

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[illegible]

APPLICATION OF: P. S. CARTER
FOR: ANTENNAE
SERIAL NO.: 460,467 FILED: June 11, 1930
DIVISION: 51 ROOM: 5628
LAST OFFICE ACTION: August 8, 1933.

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New York, N. Y., January 13, 1934.

COMMISSIONER OF PATENTS
WASHINGTON, D. C.

DEAR SIR:

In response to the Office action of August 8, 1933, please amend the above-entitled application by cancelling claims 2, 4, 37 and 38.

REMARKS

Claims 2, 4, 37 and 38 are being cancelled without prejudice.

It is not agreed that the Examiner is correct in his rejection of claims 13, 14 and 19 on the claims of an allowed application now issued to one Lindenblad assigned to the same assignee. It is assumed that the Examiner has reference to United States patent 1,927,522, granted September 19, 1933, and it is to this particular patent that applicant directs his accompanying remarks.

It is admitted that the Lindenblad patent is broad and dominates the present arrangement in some respects, but is is submitted the patent does not show the relation between the angle and the exact length of antenna as applicant teaches. A careful review will show that applicant's concept does not appear in Lindenblad's disclosure and for this reason applicant is clearly entitled to claims 13,14 and 19 as protection for his invention.

Claim 14 recites a formula which is theoretically exact and claim 15 one which is empirical. Favorable reconsideration and withdrawal of the rejection of these three claims are respectfully requested.

The rejection of claims 30, 31, 32 and 34 as not being properly illustrated because the feature "at an angle to the horizontal" is claimed particularly, has been noted. Applicant repeats his remarks hereinbefore stated in his previous amendatory paper of May 6, 1933, that the drawings adequately illustrate an antenna in a plane which may be considered either to be horizontal or at an angle inclined to the horizon, particularly so since the drawings do not show any horizontal reference and for this reason are illustrative of all antennae which have their planes either horizontal or at an angle inclined to the horizon. It is submitted that the invention is adequately described and illustrated and that any new drawing would not aid in understanding the invention further, but would, rather, clutter up the drawings and would detract from the clearness of the invention. However, if the Examiner persists applicant will be glad to present an additional showing of the antenna at an angle to the horizon, but requests that such requirement be waived for the present until these claims are allowed. Since this is a mere formality, it is thought that no objection will be raised to such a request since a showing will be forthcoming upon allowance of these claims. Inasmuch as claim 34 was previously allowed and subsequently rejected on this ground of insufficient showing it is thought that the other claims are clearly allowable with it and such action is earnestly requested.

The requirement for election between claims 23-29 and 35-36 pending allowance of a generic claim has been noted and applicant hereby elects to prosecute claims 23 to 29 pending allowance of a generic claim, such as 13, 14, 19 and 30, at which time he reserves the right to prosecute further claims 35 and 36.

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Since the generic claims are considered to be clearly allowable, it is thought that an allowance of all claims now present in this application should be forthcoming, which is requested.

Claims 3 to 12, 15 to 18, 20 to 22 and 33 stand allowed.

This application is now believed to be in condition for allowance and notice of such allowance is requested so that this application may soon pass for issue.

Respectfully submitted,

P. S. CARTER

By H. G. Grover
Attorney.

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UNITED STATES PATENT OFFICE

APPLICATION OF: P. S. Carter

FOR: Antennae

SERIAL NO: 460,467 FILED: June 11, 1930

DIVISION: 51 ROOM: 5628

LAST OFFICE ACTION: August 8, 1933

PATENT OFFICE
FEB 12 1934
DIV. 51 FILED

February 9, 1934

Hon. Commissioner of Patents

Washington, D. C.

Sir:

Please amend the above entitled application by adding the following claims:

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" K

52. A directional transmitting antenna comprising a pair of linear conductors angularly disposed with respect to each other, each of a length including substantially a plurality of half wave lengths ~~long~~ and being open-ended, a transmission line, a pair of vertical connections extending from said pair of conductors to said transmission line, and means in circuit with said transmission line for exciting the conductors in phase opposition whereby standing waves of opposite instantaneous polarity are formed on the conductors, another pair of conductors substantially similar and parallel to said first mentioned pair and spaced therefrom in a direction along the bisector of the angle of the conductors, and a pair of vertical connections in circuit with said last pair of conductors, and joining said last pair with said transmission line.

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33 ~~40~~. A directional ~~transmitting~~ antenna comprising a pair of linear conductors ~~angularly~~ disposed with respect to each other, each of a length including substantially a plurality of half wave lengths ~~long~~ and open-ended, a transmission line, a pair of vertical connections extending from said pair of conductors to said transmission line, and means in circuit with said transmission line for exciting the conductors in phase opposition whereby standing waves of opposite instantaneous polarity are formed on the conductors, another pair of conductors substantially similar and parallel to said first mentioned pair and spaced therefrom in a direction along the bisector of the angle of the conductors, and a pair of vertical connections in circuit with said last pair of conductors, said two pairs of vertical connections being joined together by a pair of horizontal conductors.

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REMARKS

Newly added claims 39 and 40 are being added to more adequately protect the present invention. These claims are drawn somewhat along the lines of allowed claim 8 and include, except for the omission of an expression in claim 6, more specific limitations than this allowed claim.

Respectfully submitted,

P. S. CARTER

by J. G. Grover

Attorney

CHB:RM

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Div. 51 Room 5628 Paper No. 13

Address only "The Commissioner of Patents, Washington, D. C." and not any official by name. EPH:HCO

DEPARTMENT OF COMMERCE
UNITED STATES PATENT OFFICE
WASHINGTON April 11, 1936

Please find below a communication from the EXAMINER in charge of this application.

APR. 11 1934

Applicant: E. J. Carter

A. G. Seever,
c/o Radio Corp. of America,
30 Rockefeller Plaza,
New York, N.Y.

Ser. No. 460,467
Filed June 11, 1930
For Antennae

Responsive to amendments filed January 13 and February 19, 1936

Additional record is made of:

Lindenblad 1,027,822 Sept. 19, 1933 250-33.1

Claims 13, 14 and 19 are again rejected as unpatentable over the Lindenblad patent cited above assigned to the same assignee. These claims differ from this reference only in the recitation of a particular specific design of the antenna conductors clearly within the scope of the claims of that patent. If applicant persists in claiming this specific arrangement it is requested that some authority in support thereof be cited.

It further appears, that in even such a claim can be established, the claims should include therein a statement of the improvement in result as well as the specific design limitations.

Since applicant's presentation of claims in the original application constituted an election of species, which as pointed out excludes the form illustrated in Figs. 10 and 10a election of such species can not be made. However, since it appears that in accordance with the holding of the Examiner of Classification claims reading on Fig. 5 read also on Fig. 8 action on the merits of those claims is made in this action.

While no complete action is made on claims 23-29 at this time it is pointed out that in claims 24 and 26-29 applicant calls for two pair of V-shaped antennas, placed so as to form a parallelogram. It appears that this structure is erroneous since two pair of such antennas would be four V-shaped elements and applicant has not disclosed such a structure. Also, the term "face each other" as used in claims 26, 28 and 29 does not properly define the structure and that the proper space relation of the antenna elements is not fully defined in certain of the claims.

Claim 30 is rejected as not being patentably distinct from Lindenblad cited above. In that reference it is clearly pointed out that the antenna may be in a vertical plane, which construction clearly meets the qualification "disposed in a plane at an angle from the horizontal".

Claims 31, 32 and 34 are rejected as being indefinite in the term "disposed in a plane at an angle to the horizontal". In the specification applicant defines this plane as inclined to the horizontal in the desired direction of transmission. It appears that this is the only such angular system disclosed and accordingly should be so claimed.

Claims 35 and 36 are rejected as being incomplete since they do not define the position of the units definitely. It appears that the units arranged "side by side" must also have their angles opening in the same direction to completely define the structure.

Claims 5-12, 15-18, 20-22, 33, 39 and 40 appear to be allowable.

In view of the age and status of this application, applicant is urged to reply promptly placing this application in condition for final adjudication.

D. D. Basing
Examiner

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IN THE UNITED STATES PATENT OFFICE

APPLICATION OF	PHILIP S. CARTER
FOR	ANTENNAE
SERIAL NO. 460,467	FILED JUNE 11, 1930
DIVISION 51	ROOM 5628
LAST OFFICE ACTION	APRIL 11, 1934

New York, New York May 2, 1934

HON. COMMISSIONER OF PATENTS
WASHINGTON, D. C.

SIR:

In response to Office Action of April 11, 1934, please amend as follows:

Cancel page 1 and rewrite same as follows:

This invention relates to directive antenna systems, and has for its primary object to provide a simplified and highly efficient antenna system utilizing standing wave phenomena.

It is known that when a wire having a length greater than the operating wave length is excited in such manner that standing waves are produced thereon, radiation will occur principally in the direction of symmetrical cones having their apices at the center of the wire. Such is the case with a wire having a length equal to a plurality of one-half wave lengths at the operating frequency. The radiation pattern produced in such instance appears, in cross section, in the form of symmetrical cones about the wire. The present invention, which makes use of these phenomena, in its most simple aspect employs a pair of open-ended wires energized in phase opposition to have standing waves throughout the length of the wires, the wires having such angular relation with respect to each other as

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to obtain a highly directional, efficient and simple antenna system. It is proposed to place these wires at an angle with respect to each other so that principal radiation takes place along the bisector of the angle. This angle, in general, corresponds to the angle of the principal cone of radiation of one of the conductors.

Another object of the invention is to disclose the angle for the best directional propagation for open-ended wires of any finite length, preferably longer than the operating wave length, having standing waves thereon and arranged in the manner proposed.

Since a pair of wires of the type above de-
of [illegible] and instantaneous polarity
scribed having standing waves thereon which are angularly disposed with respect to each other, radiate equally well in two directions, i.e., towards the diverging ends of the wires and towards the converging ends of the wires, such an ar-
rangement is bidirectional.
~~rangement is known as a bidirectional system.~~

Page 3, line 1, after "invention" insert --therefore--;
line 2, change "is" to --may preferably be--;
line 7, change the semi-colon to a comma;
line 9, after "is" insert --a--;
line 11, change "To" to --A still further object is to--; same line, cancel the comma after "plane";
line 12, before "usually" insert --(which is--;
line 13, after "planes" change the comma to a closed parenthetical mark as --)--.

Page 7, line 14, cancel "is a further object of the present invention; and," and substitute --and--.

line 19, cancel "To additionally" and substitute: --In order to further--;

line 20, change "hereinbefore" to --[illegible]--;

Cancel lines 15 and 20 and substitute:

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--Other objects and features will appear in the subsequent detailed description referring to the various embodiments of the invention disclosed in the accompanying drawings.--

Page 8, rewrite the first sentence as follows:

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--In general, as shown in Figure 1a, there are two principal hollow cones 4, 6 of radiation about a wire such as indicated by the reference character 2, which is long relative to the working wave length.--

line 4, after "2" insert a comma;

line 5, change "wire, at" to --wire having--;

line 10, change "wire," to --wire which is--;

same line, change "having" to --and has--;

line 12, before "for" insert --there are five ears in each quadrant--;

line 13, cancel "there are five ears in each quadrant,--;

line 15, change "direction" to --directions--;

line 16, change "each ear is" to --alternate ears are--;

line 22, after "used" insert --each of--;

line 24, change "occur mainly" to --mainly occur--.

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Page 6, line 4, after "wire" insert --a one--;

line 11, change "legend" to --letter--;

line 7 from the bottom, before "the wire" insert --at which--; same line, cancel "at";

lines 5 and 6 from the bottom, cancel "The obtaining of" and insert --Obviously--;

line 4 from the bottom, change "obviously, be readily" to --readily be--;

Page 7, lines 1 and 2, change the location of "is sufficiently accurate" to before --where 1--;

line 19, insert a comma after "..";

line 21, change "for," to --since--;

line 25, cancel "in phase opposition" and substitute --obtained from line 10--;

line 26, before the period insert --whereby the conductors are excited in phase opposition--;

lines 26 and 27, cancel "such that there is no reflection along transmission line 10";

last line, cancel the period and add:

-- in order that there may be no reflection along transmission line 10.--.

Page 8, line 5, after "loop" insert --itself--;

line 8, change "or" to --to be--;

line 9, before "line" insert --transmission--;

rewrite lines 16-18, inclusive, as follows:

—It should be noted that energy should always be fed to the radiators A,B out of phase, otherwise at a distant point P along the axis X-X there would be radiation cancellation instead of addition. It is also to be distinctly understood that the unit so far described, is not only useful for radiation purposes in a transmitting arrangement but may be—

Page 8, line 23, cancel "Moreover, it should be clearly" to --It is to be further--;

line 24, change "length whatsoever" to --desired length--;

line 25, before "length" insert --particular--;

line 29, change "but," to --although--;

lines 29 and 30, cancel the commas;

line 30, before "due" insert --herein--;

line 31, cancel the second comma.

Page 9, line 3, change "Here," to --In Figure 4,--;

line 10, cancel "and";

Second paragraph, lines 2-4, rewrite the second sentence to read as follows:

~~--With~~ respect to wires which are several wave lengths long, it should be noted that vertical radiation is either zero or practically very small.--;

line 6, (second paragraph) change "Specifically, it" to --More specifically, vertical radiation--.

Page 10, rewrite the first paragraph as follows:

--In order to obtain a unidirectional radiation characteristic, pairs of parallel units such as shown in ~~Figure 6~~ Figures 4a, 4b and 4c may be spaced apart a distance along the axis X-X, which in effect is the bisector of the angle formed by each pair of wires in each unit. This distance may, in the preferred arrangement, be equal to an odd number of quarter wave lengths.--;

line 18, after "with" insert --respect to--;

line 28, after "units" insert --, there are provided--;

lines 28 and 29, cancel "are provided," and substitute --which are--.

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Page 11, line 1, after "desired" insert a comma;

line 4, change "broadside and" to

--broadside with other units, and the several units--;

line 5, after "plan" insert --view--;

line 6, change "Through" to --By means of--;

line 7, insert a comma after "lines" and after "T";

Rewrite claims 13 and 14 as follows:

9 ~~11.~~ An antenna system comprising a pair of linear conductors, said conductors being angularly disposed with respect to each other, each substantially an odd number of half wave lengths long and angularly disposed with respect to each other at an angle substantially equal to the angle for which the field strength at a distant point lying in the direction of the bisector is a maximum, said field strength being proportional to

$$\frac{\cos\left(n\frac{\pi}{2}\cos\theta\right)}{\sin\theta}$$

where n is the number of half wave lengths contained in each conductor and θ is the half angle between the wires, and means in circuit with said antenna for exciting the conductors in phase opposition whereby standing waves of opposite instantaneous polarity are formed on the conductors throughout their length.

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10. An antenna comprising a pair of linear conductors each substantially an even number of half wave lengths long and disposed with respect to each other at an angle substantially equal to the angle for which the field strength at a distant point lying in the direction of the bisector is a maximum, said field strength being proportional to

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$$\frac{\sin\left(n\frac{\pi}{2}\cos\theta\right)}{\sin\theta}$$

where n is the number of half wave lengths contained in said conductor and θ is the half angle between the wires, and means in circuit with said antenna for exciting the conductors in phase opposition whereby standing waves of opposite instantaneous polarity are formed on the conductors throughout their length.

Claim 19, line 3, after the insertion add: --, and means in circuit with said antenna for exciting the conductors in phase opposition whereby standing waves of opposite instantaneous polarity are formed on the conductors throughout their length.--.

Claim 24, line 2, change "two pairs" to --a pair--.

Claim 25, line 6, before "angles" insert:

--open ends of one pair point in a substantially opposite direction with respect to the open ends of the other pair and the acute--

line 7, change "each pair" to --said pairs--.

Claim 26, line 2, change "two pairs" to --a pair--.

Claims 28 and 29, lines 1 and 2 of each claim, change "two pairs" to --a pair--; line 3 of each claim, change "angles" to --acute angle--.

Cancel claim 30.

Claim 31, line 3, cancel "each" and substitute:

--said plane extending in the desired direction of transmission, each conductor being--;

Claim 32, line 5, after the comma insert --said plane extending in the desired direction of transmission,--

Claim 33, last line, after "spacing" insert --along the bisector--.

Claim 34, line 5, after the comma insert:

--said plane extending in the desired direction of transmission,--.

Claims 35 and 36, line 5 of each claim, after "side" and before the comma insert --and have their/angles opening in the same direction--.

Claim 35, line 7, change "bisector" to --bisectors--.

Add the following claims.

39 40. An antenna arrangement comprising a pair of conductors ~~each~~ of a length including several half wave lengths long at the operating frequency, said conductors being angularly disposed at an acute angle with respect to each other, each conductor making the same angle with, but lying on opposite sides of a line representing the desired direction of ~~or~~ radiant action, and a U-shaped metallic circuit having legs substantially parallel to each other connected between substantially opposite points on said angularly disposed conductors, which points are relatively close together.

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35 ~~47~~. An antenna arrangement comprising a pair of conductors each of a length including several half wave lengths ~~long~~ at the operating frequency, said conductors being angularly disposed with respect to each other, each conductor making the same angle with, but lying on opposite sides of a line representing the desired direction of radiant action, and a circuit having conductors substantially parallel to each other connected between substantially opposite points on said angularly disposed conductors, which points are relatively close together, and means for effectively connecting together for high frequency currents, similarly located points on each of said parallel conductors.

36 ~~48~~. An antenna arrangement comprising a pair of conductors each of a length including several half wave lengths ~~long~~ at the operating frequency, said conductors being angularly disposed with respect to each other, each conductor making the same angle with, but lying on opposite sides of, a line representing the desired direction of radiant action, a U-shaped circuit having legs substantially parallel to each other connected between substantially opposite points on said angularly disposed conductors, which points are relatively close together, and a transmission line connected to the legs of said U-shaped circuit and to said angularly disposed conductors for energizing said conductors in phase opposition.

37. A directional antenna comprising a pair of angularly disposed substantially straight conductors, said conductors being angularly disposed with respect to each other,

PWK each conductor ~~being~~ of a length including a plurality of half wave lengths ~~long~~ at a desired operating frequency, means for exciting the conductors in phase opposition whereby standing waves of opposite instantaneous polarity are formed thereon whereby radiant action of the system formed by said angularly disposed linear conductors is predominantly along the direction of the bisector of the angle formed by the conductors, another pair of conductors parallel and similar to said first mentioned pair of conductors, and a substantially radiationless transmission line, not less than a quarter wave length long at the desired operating frequency, joining substantially opposite points on said pairs of conductors, the points on each pair being relatively close together.

38. A directional antenna comprising a pair of straight conductors angularly disposed with respect to each

PWK other, each conductor ~~being~~ of a length including a plurality of wave lengths ~~long~~ at the operating frequency and being electrically open-ended at their most widely separated ends, means for exciting said conductors in phase opposition whereby standing waves of opposite instantaneous polarity are formed thereon, and another pair of open-ended conductors similar and parallel to said first mentioned pair of conductors and being spaced therefrom in a direction along the bisector of the angle of the conductors such that radiant action of said pairs of conductors is substantially unidirectional.

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39. A directional antenna comprising a pair of straight conductors angularly disposed with respect to each other, each conductor being of a length including a plurality of half wave lengths ~~long~~ at the operating frequency, said conductors being electrically open-ended at their most widely separated ends, another pair of open-ended conductors similar and parallel to said first mentioned pair of conductors and spaced therefrom in a direction along the bisector of the angle of the conductors, and a substantially radiationless transmission line connected between points on said pairs of conductors, the points chosen on each pair being relatively close together, said transmission line being not less than a quarter wave length long at the desired operating frequency.

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40. A directional antenna comprising two pairs of conductors, the conductors of each pair being substantially straight and being arranged so as to form substantially a V, each conductor of each of said pairs of conductors being of a length including a plurality of wave lengths ~~long~~ at the desired operating frequency, the most remote ends of the conductors of each pair being electrically open-ended, both pairs of conductors lying in the same plane and symmetrically about a line representing a desired direction of radiant action.

41 50. A directional antenna comprising two pairs of conductors, the conductors of each pair being substantially straight and being arranged so as to form substantially a V, each conductor of each of said pairs of conductors being a plurality of wave lengths long at the desired operating frequency, the most remote ends of the conductors of each pair being electrically open-ended, both pairs of conductors lying in the same plane and symmetrically about a line representing a desired direction of radiant action, and a substantially radiationless transmission line not less than a quarter wave length long connected between similar points on said pairs of conductors, the points taken on each pair of conductors being close relative to the electrical open ends of said conductors. 1519

REMARKS

Applicant is grateful to the Examiner for his very kind suggestions and has attempted to comply with all the Examiner's suggestions so that this application may pass for issue at a date as early as possible.

The specification has been extensively revised in the interest of clarity, to overcome obvious typographical errors, and to correct unidiomatic expressions.

Claims 13, 14 and 19 have been amended to recite that there are means provided for causing standing waves to exist throughout the length of the antenna conductors, a feature which applicant fails to find in Lindenblad.

Claims 13 and 14 have been further amended to overcome the objection raised by the Examiner, which, it is submitted, is not clearly understood since all apparatus claims are for "particular specific designs" no matter what their form. It is herein repeated that these claims define a precise relation between the angle and the length of the antenna, which is not to be found in the Lindenblad patent. Applicant recognizes that the Lindenblad patent broadly covers the present arrangement. However, applicant's concept of specific relations is clearly lacking in the Lindenblad disclosure, and nothing disclosed by Lindenblad appears to meet the present claims.

A somewhat similar situation appears in Hogan vs. John Wanamaker Company, 4 U. S. Pat. Q. 118, at 122, wherein the Court held in connection with two patents, one of which broadly covered a ratio between conductance and capacity in a system and the other of which recited a specific one to one ratio, that:

> "So far as the Lowenstein patent (1618017) is concerned, ...upon..reflection and hearing the arguments in this case, I am satisfied that Lowenstein in dealing with the equality of ratios between inductance and capacity in the two circuits, and particularly with their logarithmic relationship, may have necessarily included in his general conception the idea of a one-to-one ratio which is in fact what Hogan insists upon throughout.
>
> "But Lowenstein is not prior art to Hogan. To defeat the Hogan patent there must be found in Lowenstein the invention disclosed by Hogan. By that I mean that it is not enough to find in Lowenstein a statement of the theory from which one might at once conceive Hogan's idea and consummate his invention. There must, I think, be a disclosure of what he invented; otherwise Lowenstein is in the position of having conceived a general principle without reducing it to the means which constitute invention and of having overlooked that which Hogan conceived and did reduce to operative means."

Similarly, in the present citation, Lindenblad necessarily has included in his general conception the thought of a V type antenna, but he did not include the definite, precise relation between the angle and the length of the antenna for giving the best results. However, this is now considered to be a moot question since the amendments to these claims are considered to render them patentable regardless of this authority, which clearly supports applicant's contention that the claims are allowable. Reconsideration is requested.

Claims 24, 25, 26, 28, 29, 31, 32, 34, 35, and 36 have been amended along the lines suggested by the Examiner, in order to overcome such objections as indefiniteness and incompleteness, and for this reason are now considered to be allowable.

Claim 30 has been cancelled without prejudice, merely to expedite the prosecution of this case.

Claims 5-12, 15-18, 20-22, 33, 39, and 40 stand allowed.

Eight new claims, 43-50, inclusive, have been added to more adequately protect the invention. Claims 43, 44 and 45 have been drawn to read on applicant's Figure 2C and claims 46, 48 and 50 to read on applicant's Figure 5. Claim 47 is somewhat along the lines of allowed claim 5 and claim 49 is drawn somewhat along the lines of claim 47. These claims have been especially drafted in the light of the art cited and clearly distinguish thereover for reasons which it is deemed obvious from a mere reading thereof. These claims recite various limitations not to be found in the prior art, so far as applicant is aware.

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Applicant earnestly submits that he dislikes very much the piecemeal prosecution of claims, and regrets the necessity which requires that he present these claims at this time, which he believes he is clearly entitled to in order to adequately protect his invention.

In view of the fact that the claims now appearing in this application clearly distinguish over the references, it is earnestly requested that an early action be given. so that this case may pass to issue soon.

Respectfully submitted,

PHILIP S. CARTER

CRB:EB

By H G Grover
Attorney

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H

United States Patent Office

MAY 15 34

PATENT OFFICE
MAY 15 1934

Application of Philip S Carter
For Antennas
Ser No 460,467 filed June 11, 1930
Div 51 Room 5-628
Last Office Action April 11, 1934

Hon Comm of Patents: Washington, D.C May 15, 1934

Please amend the above entitled application as follows:

Claims 24, 25, 28 and 29, cancel the period in the last line and add -- , and means for connecting the apex of each V antenna to high frequency apparatus. --

Claim 27, lines 1 and 2, change "two pairs" to -- a pair --

Respectfully submitted
P.S. Carter

by H. G. Grover
Attorney

73 - R

16

IN THE UNITED STATES PATENT OFFICE

APPLICATION OF	PHILIP S. CARTER
FOR	ANTENNAE
SERIAL NO. 460,497	FILED JUNE 11, 1930
DIVISION 51	ROOM 5828

New York, New York May 15, 1934

HON. COMMISSIONER OF PATENTS
WASHINGTON, D. C.

SIR:

Please amend the above entitled application as follows:

Claim 27, lines 1 and 2, change "two pairs" to --a pair--;

Claims 24, 27, 28, and 29, last line of each claim, change the period to a comma and add:

--and means for connecting the apex of each V antenna to high frequency apparatus--.

Respectfully submitted,
PHILIP S. CARTER

By H G Grover
Attorney

CHD:EB

Duplicate Copy

Confirmation (Amendment filed) in mail May 15, 1934 in Patent Office

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Div. 51, Room 5628
ADDRESS ONLY
THE COMMISSIONER OF PATENTS
WASHINGTON, D. C.
MCG

Serial No. 460,467

DEPARTMENT OF COMMERCE
UNITED STATES PATENT OFFICE

Philip Staats Carter, Assor. WASHINGTON June 13, 1934.

Your APPLICATION for a patent for an IMPROVEMENT in
ANTENNAE
filed June 11, 1930 has been examined and ALLOWED with 41 claims.

The final fee, THIRTY DOLLARS, WITH $1 ADDITIONAL FOR EACH CLAIM ALLOWED IN EXCESS OF 20, must be paid not later than SIX MONTHS from the date of this present notice of allowance. If the final fee be not paid within that period, the patent will be withheld, but the application may be renewed within one year after the date of the original notice with a renewal fee of $30 and $1 additional for each claim in excess of 20.

The office delivers patents upon the day of their date, on which date their term begins to run. The preparation of the patent for final signing and sealing will require about four weeks, and such work will not be begun until after payment of the necessary final fee.

When the final fee is paid, there should also be sent, DISTINCTLY AND PLAINLY WRITTEN, the name of the INVENTOR, TITLE OF THE INVENTION, AND SERIAL NUMBER AS ABOVE GIVEN, DATE OF ALLOWANCE (which is the date of this circular), DATE OF FILING, and, if assigned, the NAMES OF THE ASSIGNEES.

If it is desired to have the patent issue to an ASSIGNEE OR ASSIGNEES, an assignment containing a REQUEST to that effect, together with the FEE for recording the same, must be filed in this office on or before the date of payment of the final fee.

After issue of the patent, uncertified copies of the drawings and specifications may be purchased at the price of TEN CENTS EACH. The money should accompany the order. Postage stamps will not be received.

The final fee will NOT be received from other than the applicant, his assignee or attorney, or a party in interest as shown by the records of the Patent Office.

NOTICE.—WHEN THE NUMBER OF CLAIMS ALLOWED IS IN EXCESS OF 20, NO SUM LESS THAN $30 PLUS $1 ADDITIONAL FOR EACH CLAIM IN EXCESS OF TWENTY CAN BE ACCEPTED AS THE FINAL FEE.

Respectfully,

Conway P. Coe

Commissioner of Patents.

H. G. Grover,
C/o Radio Corporation of America,
30 Rockefeller Plaza,
New York, N. Y.

IN REMITTING THE FINAL FEE GIVE THE SERIAL NUMBER AT THE HEAD OF THIS NOTICE.

UNCERTIFIED CHECKS WILL NOT BE ACCEPTED.

PAPER NO 17
AMENDMENT

4205

JUL 12 34
U.S. PATENT OFFICE

IN THE UNITED STATES PATENT OFFICE

APPLICATION OF	PHILIP S. CARTER
FOR	ANTENNAE
SERIAL NO. 460,487	FILED JUNE 11, 1930
DIVISION 51	ROOM 5628
ALLOWED	JUNE 13, 1934

Letter of Printer's Department

New York, New York
July 10, 1934

PATENT OFFICE
JUL 13 1934
DIV. 51 FILED

HON. COMMISSIONER OF PATENTS

WASHINGTON, D. C.

SIR:

AMENDMENT UNDER RULE 78

Please amend the above entitled application as follows, under the provisions of Rule 78:

Page 1, of the amendment dated May 2, 1934, line 3 from the bottom, after "energized" insert --in phase oppositi

Page 2, of the amendment dated May 2, 1934, line 13, after "waves" insert --of opposite and instantaneous polarity--;

line 17, rewrite this line as follows:

--rangement is bidirectional.--.

Page 3, of the specification, cancel the second and third paragraphs and substitute therefore:

--A still further object is to concentrate the beam in planes transverse to the plane of the wires. These transverse planes usually include the vertical plane, since the wires are ordinarily disposed in horizontal planes. This may be effected by placing similar arrangements of wires above or below a given arrangement of wires. To increase horizontal directivity, the arrangements of wires may be duplicated side by side.--

Page 3, line 5 from the bottom, change "conal" to --conical--.

Page 4, line 7, change "figure 2," to --any of the figures 2a, 2b, or 2c,--;

line 10, change "figure 2," to --figures 2a, 2b, and 2c,--;

line 13, cancel "an antenna";

rewrite line 14 as follows:

--one antenna system of particular dimensions of the type shown in figure 5,--;

line 20, before "in plan" insert --schematically--;

cancel the last paragraph and substitute:

--Figure 12 is a graph showing the relationship between the length of one of a pair of conductors and half the angle between them for obtaining maximum radiation along the bisector of said angle. As indicated by the sketch of the antenna system in the upper right hand corner of this figure, this relationship holds most strictly when the wires are of equal length.--

Page 5, line 5, change "For a given wire having a given wave length" to read:

--For a given length of wire measured in wave lengths--;

line 10, cancel "a wire which is" and substitute

--the radiation from a wire, which wire is--;

line 14, before "lobes" insert --ears of--;

cancel line 16 and substitute:

--by adjacent ears are reversed.--;

line 18, change "figure 2," to --figures 2a, 2b, and 2c,--;

line 23, cancel "radiation cancellation";

cancel lines 26-29, inclusive, and substitute:

--addition of radiation from the two wires is imperfect, and at certain angles radiation cancellation will occurs. Consequently, a pair of wires disposed at the angle α with respect to the X-X axis will have a

radiation characteristic in the plane of the pair of wires of the general type shown in figure 3.

Page 6, last paragraph, line 2, cancel ", of course,";

line 3, cancel "the wire" and substitute:

--each wire of the V--;

not entered line 5, change "the critical" to --this--.

Page 7, cancel line 3 and substitute:

--A pair of wires of substantially equal length are used to form the V antenna of the present invention,--

line 4, after "angle" (first occurrence) insert --substantially--;

line 8, change "figure 2" to --figures 2a, 2b, or 2c--;

line 15, change "are" to --may be--;

line 17, cancel "of course,";

cancel lines 18 and 19, and substitute:

--2b, the radiating wires may be terminated on a transmission line 10 instead of being connected together at the apex as shown in figure 2a.--

line 20, cancel ", however,";

line 21, change "allows of" to --facilitates--;

not entered line 23, after "are" insert --bridged or--;

not entered line 24, before "short" insert --bridging or--;

cancel the addition to the last line, and substitute:

--in order that reflection along transmission line 10 may be reduced.--

Page 8, line 3, after "unit" insert --substantially --;

line 5, after "is" insert --substantially--;

not entered line 10, change "short circuiting" to --bridging--;

lines 14-15, cancel the insertion made therein and substitute:

--It should be noted that energy should be fed

so as to energize the radiators A,B in phase opposition, otherwise at a distant point P along the axis X-X there would be radiation cancellation instead of addition. It is also to be distinctly understood that the unit, so far described, is not only useful for radiation purposes in a transmitting arrangement but may be..;

lines 24 and 25, cancel "provided they are placed at the correct angle for their particular length." and insert a period after "desired length" in line 24.

line 3 from the bottom, change "where" to --whether or not--;

line 2 from the bottom, change "does not correspond to a whole" to --corresponds to an integral--.

Page 9, cancel line 11 and substitute:

--by a substantial spacing of preferably not less than one-half wave--.

line 12, cancel "apart";

line 17, cancel "With respect";

cancel lines 18-22, inclusive;

line 23, change "approaches" to --For wires whose lengths approach--.

Page 10, in the paragraph substituted for the first paragraph by amendment dated May 2, 1934, line 3, change "Figure 2" to --figures 2a, 2b, and 2c--.

Page 10, line 29, cancel "32, 32'." and insert --at 32, 32', similar to 14 at figure 2c and as shown in figure 11.--;

line 30, cancel "Of course, any" and substitute --By--.

Page 11, line 7, insert a comma after "lines";

line 14, cancel "By making the phase differ-";

cancel lines 15-20, inclusive, and substitute:

--By employing a large number of units, as illustrated, and following the principles of spacing and phasing set forth herein, great directivity may be obtained.--.

not entered

Page 12, line 15, change "12" to --10--;

line 21, change "should" to --may--;

line 22, cancel "for maximum concentration,";

line 23, change "length" to --lengths--;

line 25, cancel ", of course,";

line 27, start a new paragraph with the sentence starting "The wires,";

Add the following paragraph at the end of the page:

--By the term "plurality of wave lengths", or "plurality of half wave lengths", or "several half wave lengths" appearing in the appended claims, it is not intended that the wires so described shall necessarily be an exact or approximate integral number of such lengths, but rather that each of the wires so described shall be sufficiently long to include the lengths specified, as is evident from a reading of the specification and drawings.--.

not entered

Claim 7, line 2, cancel the insertion therein and substitute:

--said conductors being angularly disposed with respect to each other--.

Claim 42, line 6, cancel "a" (second occurrence).

Claim 47, line 3, after "of" insert --half--.

Claim 50, next to the last line, after "close" insert --together--.

REMARKS

The above amendments to the specification and claims are intended to clarify the specification and certain of the claims by overcoming ambiguous expressions and obvious inadvertent typographical errors.

In view of the very minor changes made, it is not believed necessary to enter into any discussion with regard to the amendments.

A separate letter is being sent to the Office draftsman requesting him to insert two reference characters, omitted from figure 11, and to correct the omission of two bridging taps in figure 5, in the manner indicated in red ink on the accompanying prints. A mere reading of the specification will show that these corrections are intended to overcome inadvertent errors on the part of the draftsman.

A supplemental Oath, properly signed and executed, accompanies this amendment. It is requested that this Oath be entered for purposes of the record.

Early notice of the entrance of this amendment under Rule 78 is respectfully requested.

Respectfully submitted,
PHILIP S. CARTER

By H.S. Grover
Attorney

CHB:EB

ENTRY RECOMMENDED in part
UNDER RULE 78
C.D. Brashay
EXAMINER

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#17 [illegible]

U. S. PAT

JUL 12

[illegible] DIVIS

[illegible] DIVISION
JUL 12 34
U.S. PATENT OFFICE

IN THE UNITED STATES PATENT OFFICE

In re: Philip S. Carter	:	
Serial No. 460,467	:	Division 51
Filed June 11, 1930	:	Room 5628
Antennas	:	Allowed June 1?, 1934

PATENT OFFICE
JUL 13 1934
DIV. 51 FILED

SUPPLEMENTAL OATH

State of New York)
) ss:
County of Suffolk)

PHILIP S. CARTER, whose application for Letters Patent for an improvement in ANTENNAE, Serial No. 460,467, was filed in the United States Patent Office on or about the 11th day of June, 1930, being duly sworn, deposes and says that the subject matter of the amendment under Rule 78, filed herewith, and all previous amendments, including, specifically, those filed on November 17, 1931, August 6, 1932, February 10, 1934, and May 3, 1934, was part of his invention, was invented before he filed his original application, above identified, for such invention, was not known or used before his invention, was not patented or described in a printed publication in any country more than two years before his application, was not patented in a foreign country on an application filed by himself or his legal representatives or assigns more than twelve months before his application, was not in public use or on sale in this country for more than two years before the date of his application, and has not been abandoned.

Philip S. Carter

Sworn to and subscribed before me this 10. day of July, 1934.

Ludwig A. Battermann
Notary Public
LUDWIG A. BATTERMANN
NOTARY PUBLIC,
Suffolk County.
Commission Expires March 30th, 1935

Seal.

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U. S PATENT OFFICE 4205

JUL 12 1934

DIVISION

MAILED
JUL 12 34
US PATENT OFFICE

2 prints

IN THE UNITED STATES PATENT OFFICE

APPLICATION OF	PHILIP S. CARTER
FOR	ANTENNAE
SERIAL NO. 460,467	FILED JUNE 11, 1930
DIVISION 51	ROOM 5658
ALLOWED	JUNE 13, 1934

JUL 13 1934

New York, New York
July 10, 1934

ACCOUNT

HON. COMMISSIONER OF PATENTS
WASHINGTON, D. C.

SIR: ATTENTION: OFFICE DRAFTSMAN

Please instruct the Office draftsman to correct Fig. 5 and Fig. 11 as indicated in red ink on the accompanying print.

The cost of this work is to be charged to the account of Radio Corporation of America.

Respectfully submitted,
PHILIP S. CARTER

RECEIVED IN DIV. 8
JUL 14 1934

CHB:EB

By H. G. Grover
Attorney

Encl.

RECOMMENDED
UNDER RULE 78
D. D. Backus
EXAMINER

CORRECTION ORDERED
JUL 14 1934
ACCOUNT

DIV. C
CORRECTED
JUL 14 1934

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Fig. 3

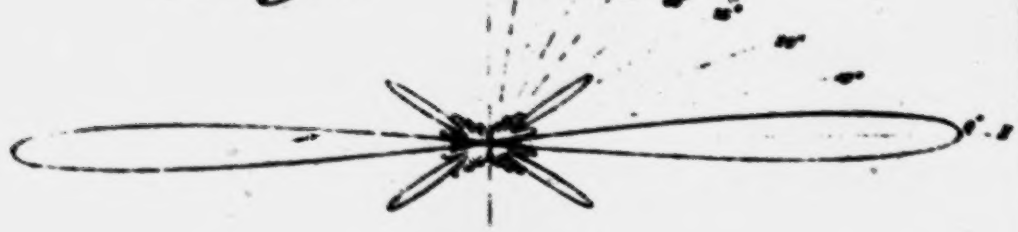
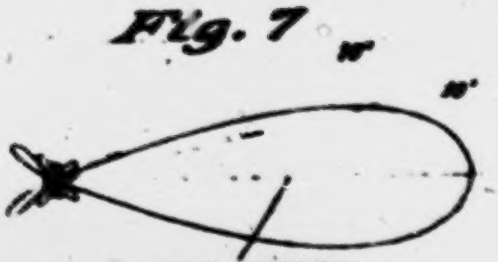


Fig. 4

Fig. 5

Fig. 6

Fig. 7



INVENTOR
P. S. CARTER
BY
ATTORNEY

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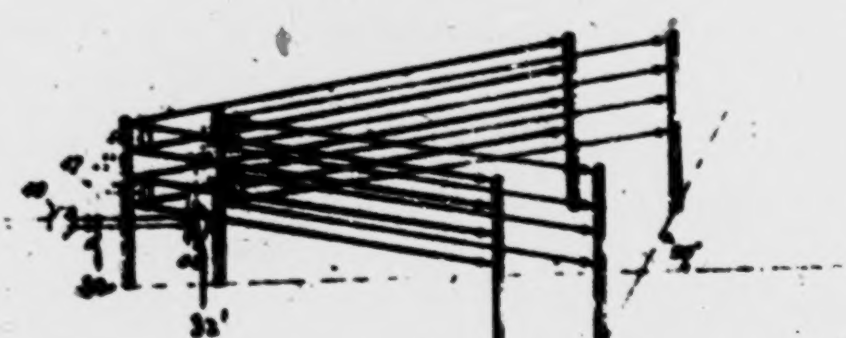
Fig. 8

Fig. 10 Fig. 10a

Fig. 9

Fig. 11



INVENTOR
P. S. CARTER
BY H G Grover
ATTORNEY

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DEPARTMENT OF COMMERCE
UNITED STATES PATENT OFFICE
WASHINGTON

July 17 1935

Petition under **RULE 78:**

MAILED
JUL 18 1935

Application of

Serial No.

Invention:

This petition is referred to Examiner in charge of Division 51 in accordance with Order No. 2698; Order No. 2801, 306 O. G., 447, and Notice of August 11, 1922.

Conway P. Coe
86
Commissioner.

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1121

DEPARTMENT OF COMMERCE
UNITED STATES PATENT OFFICE
WASHINGTON

Paper No. 18

July 16, 1934.

Applicant: P. S. Carter

E. G. Grover,
C/o Radio Corp. of America,
30 Rockefeller Plaza,
New York, N. Y.

Ser. No. 460,467
Filed June 11, 1930
For Antenna

The entry of the amendment proposed under Rule 78 has been disapproved. A copy of the examiner's adverse report appears below.

JUL 19 1934

Commissioner of Patents

The amendment proposed is more extensive than is contemplated under Rule 78 and contains many proposed changes of questionable propriety. However, most of the changes are approved but the following changes are not approved.

On page 3 of the amendment lines 6, 21, 22 and 28; page 4, lines 9-14, and page 5, lines 1-7 as these changes modify the disclosure to too great an extent.

On page 4, lines 19-22, the proposed changes render this portion incomplete and indefinite.

On page 5, lines 14-28 the additional paragraph is considered unwarranted.

And page 5 the amendment to claim 47 changes the meaning thereof.

The amendment is approved and has been entered except for the above specified exceptions.

The amendment to the drawing has been approved.

O. D. Backus
Examiner

APPROVED

JUL 17 1934

MAIL ROOM
AUG -3 1934
PATENT

PATENT OFFICE
AUG 3 1934
DIVISION

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PATENT OFFICE
AUG 4 1934

IN THE UNITED STATES PATENT OFFICE

APPLICATION OF PHILIP S. CARTER	
FOR ANTENNAE	
SERIAL NO. 460,467	FILED JUNE 11, 1930
DIVISION 51	ROOM 5626
ALLOWED	JUNE 13, 1934

New York, New York. August 2, 1934

HON. COMMISSIONER OF PATENTS
WASHINGTON, D. C.

Rule 78

AMENDMENT UNDER RULE 78

SIR:

Please amend the above entitled application under the provisions of Rule 78, as follows:

✓ Page 8, line 3 from the bottom, change "where" to --whether or not--.

✓ line 2 from the bottom, change "does not correspond to a whole" to --corresponds to an integral--.

✓ Page 9, line 17, cancel "With respect";

cancel lines 18-22, inclusive, including the insertion appearing for these lines;

✓ line 23, change "approaches" to --For wires whose lengths approach--.

✓ Page 12, add the following paragraph at the end of the page

By the term "plurality of wave lengths", or "plurality of half wave lengths", or "several half wave lengths", it is not intended that the wires so described shall necessarily be an exact or approximate integral number of such lengths, unless so specified, but rather that each of the wires so described shall be sufficiently long to include the lengths specified.

K'

Claims [illegible], [illegible], [illegible], [illegible], [illegible] and 10, line [illegible] of each claim, before "sub [illegible]" insert --of a length including--;
line 3 of each claim, cancel "long".

Claims [illegible] and [illegible], line [illegible] of each claim, after "[illegible]" insert --being--.

Claim [illegible], line [illegible], after "each" (second occurrence) insert --of a length including--;
line [illegible], change "long and" to --and being--;
line 5, after "[illegible]" insert --of a length including--
same line, change "long and" to --and being--.

Claim [illegible], line [illegible], before "substan-" insert --of a length including--;
line 4, cancel "long".

Claim [illegible], line [illegible], after "each" (second occurrence) insert --of a length including--;
line 4, cancel "long and" and substitute --and being--

Claims [illegible] and [illegible], line 3 of each claim, after "each" (second occurrence) cancel "conductor being" and substitute --conductor being of a length including--;
line 4 of each claim, cancel "long and" and substitute --and being--.

Claims 39 and 40, line 3 of each claim, before "substantially"

insert --of length including--;

line 4 of each claim, change "long and" to

--and being--.

Claims 43, 44 and 45, line 2 of each claim, after "each" —

insert --of a length including--;

same line of each claim, cancel "long".

Claim 46, line 4, after "being" insert --of a length

including--;

same line, cancel "long".

Claim 47, line 3, after "being" insert --of a length including--;

same line, cancel "long".

Claim 48, line 3 after "being" insert --of a length

including--;

line 4, cancel "long".

Claims 49 and 50, line 4 of each claim, after "being" insert

--of a length including--;

line 5 of each claim, cancel "long".

R E M A R K S

In accordance with the interview kindly granted applicant's attorney, applicant is presenting herewith several amendments to the application under the provisions of Rule 78. These amendments are similar or identical in scope with those previously presented by applicant in his amendatory paper dated July 5, 1934, and which were not approved by the Examiner. These amendments, it is earnestly submitted, are intended to overcome expressions of poor form and ambiguous terminology.

The addition of the paragraph at the end of page 12 is intended to clear up any possible ambiguity which might exist due to a misinterpretation of the phraseology of the specification and claims. This paragraph, it is to be noted, is now in the form approved by the Examiner, in that it no longer can be interpreted as effecting an amendment to the claims, and therefore of "questionable propriety" under Rule 78. As suggested at the interview, claims 5-10, inclusive, 25, 31, 32, 33, 34, 38, 40, and 43-50, inclusive, have now been amended to conform to the phraseology of the previously requested insertion at the end of page 12.

At this time applicant's attorney desires to express his appreciation of the Examiner's explanation that the characterization of certain previously proposed amendments as "of questionable propriety", in the first paragraph of the Office Letter of July 18, 1934, was intended as a statement that applicant could not, as a matter of right, require the entrance of these amendments under Rule 78, and that the Examiner agrees that the proposed changes were properly within the scope of the invention, as described in the application. We are grateful for the further assistance that the Examiner has given in the present effort to remove all ambiguities from this highly technical application.

Respectfully submitted,

PHILIP S. CARTER

By ________________
Attorney

CHD:SB

AMENDMENT APPROVED

ACTING COMMISSIONER OF PATENTS

ENTRY RECOMMENDED UNDER RULE 78

EXAMINER

DEPARTMENT OF COMMERCE
UNITED STATES PATENT OFFICE
WASHINGTON

Aug 15 1934

Petition under **RULE 78:**

MAILED
AUG 8 1934

Application of

Serial No.

Invention:

This petition is referred to Examiner in charge of Division 51 in accordance with Order No. 2800; Order No. 2801, 300 O. G., 447, and Notice of August 11, 1922.

Conway P. Coe
92 R Commissioner

Div. 51 Room 5428 DEPARTMENT OF COMMERCE Paper No. 90
UNITED STATES PATENT OFFICE
MOO WASHINGTON August 6, 1934.

Applicant: Philip S. Carter

H. G. Grover,
C/o Radio Corp. of America,
30 Rockefeller Plaza,
New York, N. Y.

Ser. No. 460,467
Filed June 11, 1930
For Antennae

The amendment proposed has been entered under Rule 78.

Conway P. Coe
Commissioner of Patents

MAILED
AUG 8 1934

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U. S. PATENT OFFICE
AUG 24 1934
[illegible] DIVISION

UNITED STATES PATENT OFFICE

PATENT OFFICE
AUG 22 1934
DIV. FILED

APPLICATION OF: PHILLIP S. CARTER
FOR: ANTENNAE
SERIAL NO. 460,467 FILED: June 11, 1930
DIVISION: 51 ROOM: 5628
LAST OFFICE ACTION: AUGUST 8, 1934

New York, N. Y., August 21, 1934.

COMMISSIONER OF PATENTS
WASHINGTON, D. C.

DEAR SIR:

AMENDMENT UNDER RULE 78

In accordance with the provisions of Rule 78, kindly amend this case as follows:

Claim 23, last line, before the period insert -- , the conductors of each pair being excited in phase opposition whereby radiant action occurs principally in the plane of said conductors and along the direction of said bisector --.

L'

Claim 24, rewrite the last line as follows: -- a pair of V-shaped antennae arranged to form a parallelogram, and means for connecting the apex of each V antenna to high frequency apparatus whereby the legs of each V which lie alongside each other are excited in phase opposition so that radiant action occurs principally in the plane of the V-shaped antennae and principally in a direction along a line joining the apices of said V-shaped antennae --.

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Claim 26, last line, before the period insert --whereby radiant action occurs principally in the plane of said radiators and principally along a line joining the apices of said V-shaped antennae--.

Claim 27, rewrite the last line as follows: directions with respect to the other pair, and means for connecting the apex of each V antenna to high frequency apparatus whereby radiant action occurs principally in the plane of the V-shaped antennae and principally in a direction corresponding to the line joining the apices of said V-shaped antennae.

Claim 28, rewrite the last line as follows: --in different directions, and means for connecting the apex of each V antenna to high frequency apparatus whereby radiant action occurs principally in the plane of the V-shaped antennae and principally in a direction corresponding to a line joining the apices of said V-shaped antennae.

Claim 29, rewrite last line as follows: other, and means for connecting the apex of each V antenna to high frequency apparatus whereby radiant action occurs principally in the plane of the radiators and principally in a direction corresponding to a line joining the apices of said V-shaped antennae.

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REMARKS.

In order to direct claims 23, 24, 26, 27, 28 and 29 more closely about the subject matter which they are intended to cover, the foregoing changes have been made. Inasmuch as the amendments to the claims are not of such nature as to require further search, it is believed that no objection will be made to their entry and, consequently, early notice thereof is respectfully requested.

Respectfully submitted,

PHILIP S. CARTER

By H. G. Gross
Attorney.

HT:EC

ENTRY RECOMMENDED
UNDER RULE 78

C. D. Beaton
EXAMINER

[illegible]

ACTING COMMISSIONER OF PATENTS

DEPARTMENT OF COMMERCE
UNITED STATES PATENT OFFICE
WASHINGTON

Aug. 22, 1934

MAILED
AUG 25 1934

Petition under RULE 78:

Application of

Serial No.

Invention:

This petition is referred to Examiner in charge of Division 51 in accordance with Order No. 2888; Order No. 2891, 388 O. G., 447, and Notice of August 11, 1928.

460467 Conway P. Coe
97 R

Div. 51 Room 5480

DEPARTMENT OF COMMERCE
UNITED STATES PATENT OFFICE
WASHINGTON

Paper No. 28

MCO

August 23, 1934.

Applicant: Philip S. Carter

H. S. Grover,
C/o Radio Corp. of America,
30 Rockefeller Plaza,
New York, N. Y.

Ser. No. 460,467
Filed June 11, 1930
For Antennae

The amendment proposed has been entered under Rule 78.

Conway P. Coe

Commissioner of Patents

MAILED
AUG 25 1934

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AUG 23 34 37491 R - [illegible] - 30.00

[illegible] 37371 R - [illegible] - 21.00

FINAL FEE PAID TO THE COMMISSIONER OF PATENTS

(Be careful to give correct Serial No.)

Serial No. 460,407

INVENTOR:

P. D. Carter

PATENT TO BE ISSUED TO

Radio Corporation of America

NAME OF INVENTION, AS ALLOWED:

DATE OF PAYMENT:

August 23, 1934

FEE:

Fifty One Dollars

DATE OF FILING:

June 11, 1930

DATE OF CIRCULAR OF ALLOWANCE:

The Commissioner of Patents will please apply the accompanying fee as indicated above.

[illegible]

Attorney.

SEND PATENT TO

Radio Corporation of America

Patent Department

30 Rockefeller Plaza New York N.Y.

Final fee will not be received from other than the applicant, his assignee or attorney, or a party in interest as shown by the records of the Patent Office, NOR WILL THEY BE APPLIED IN PENDING APPLICATIONS

P

4. Patent No. 1,927,522 issued to Nils E. Lindenblad assignor to Radio Corporation of America for Antenna for Radio Communication, granted September 19th, 1933, on an application filed December 24th, 1928, of which claims 9, 10, 19, and 23 are in suit. This patent will be hereinafter referred to as the second Lindenblad patent.

5. Patent No. 1,974,387 issued to Philip Staats Carter assignor to Radio Corporation of America for Antenna, granted September 18th, 1934, on an application filed June 11th, 1930, of which claims 1, 2, 3, 4, 10, 12, 15, 16, 28, 34, 35, 36, 38 and 40 are in suit. This patent will be hereinafter referred to as the third Carter patent.

The first two Carter patents are directed to the subject of impedance matching. The two Lindenblad patents and the third Carter patent are directed to the subject of antennas. I will consider them in the two respective groups.

The defendant by answer has pleaded the defenses of invalidity and non-infringement.

[fol. 1347] The title to the patents in suit is in the plaintiff and notice of infringement was properly given.

There is no dispute as to the construction or arrangement of the defendant's antenna systems and they are fully described in the agreed descriptions, diagrams and tabulations of dimensional data comprising Plaintiff's Exhibits 7 to 13, inclusive. The antennas which are asserted to infringe are known as V-antennas Nos. 1 to 11, inclusive (two of which have been rebuilt) and certain other antennas known as "dipole arrays". The antennas referred to as having been rebuilt are obviously defendant's antennas Nos. 2 and 3, the rebuilding of which was occasioned by commercial requirements of establishing additional communication channels in a different direction from that in which they had previously been used. Various alterations occurred in the rebuilding process and as these rebuilt antennas were not rebuilt until after the main and supplemental bills of complaint were filed in this suit, they cannot properly be considered by this Court under the charge of infringement on the pleadings in this suit.

The desirability for, and the utilization of an impedance matching arrangement was known many years prior to the earliest date which could be claimed by Carter. In the transmission of electrical energy over a line, whenever, as

is usually the case, the impedance of the load differs from the impedance of the transmission line, energy will not flow smoothly into the load, but part of it will be reflected back into the line towards the source of power, and cause "reflection", "standing waves", "reflection loss", etc. Also, when there is a sharp bend in a transmission line a difference [fol. 1348] of impedance results which causes reflection. If, however, the impedance of the load is matched to the impedance of the line there are no reflected waves, and there is obtained what is termed a "reflectionless line", "a traveling wave", a "line of electrically infinite length", etc. These terms (as well as others mentioned on the trial and in the briefs herein) are synonymous and the desirability for impedance matching, as well as the means employed for effecting it, is not concerned with the purpose for which the current being transmitted is used. I can see no difference whether impedance matching be effected in a radio receiving system, a radio transmission system, a telephone line, a power line or in any circuit. The second Carter patent in suit is entitled "Electrical Circuit" and is applicable to any circuit arrangement where efficient transfer of energy, without reflection is desired. Unequal impedance is always the cause of reflected waves and the cure is always equal or matched impedance.

Impedance matching devices for the purpose of preventing reflection on transmission lines have been used for many years in radio transmitting systems, at least, since 1920, and as the first Carter patent in suit was not applied for until 1923 there was nothing novel at that date in the necessity for matching impedances, or in the principle that by matched impedances reflected waves on the transmission line were avoided.

The First Carter Patent No. 1,623,996

This patent is directed to the subject of a reflectionless transmission line obtained by matching the surge impedance [fol. 1349] of the line with the load impedance of the antenna which it feeds. A transformer is the only means shown or suggested for accomplishing that purpose, and two forms of transformers are illustrated, namely the usual two coil transformer illustrated in Figs. 1, 3 and 5, and the auto (one coil) transformer of Fig. 2.

It is pointed out in the patent that in the past it has been the custom to erect the antenna of a transmitting system as close as possible to the point when the radio frequency power is generated in order to have "a minimum power loss between the generator and the antenna". The patentee in his specification states the objects of his invention to be as follows:

"the provision of a transmission line which will supply radio frequency energy from a power-house to an antenna located at a considerable distance away, thus making possible the utilization of existing apparatus at a high efficiency where hitherto only a low efficiency was possible. Another object of the invention is to provide a new and improved system giving directional transmission utilizing separate antennæ fed from a single source through a plurality of transmission lines."

Claims 1, 2 and 5 have to do only with the first stated object. Claim 7 has to do only with the second stated object.

It is pointed out in the specification that in order to attain the first object of the invention it is ecessary that the apparatus work

"at unity power factor; that is to say that the current and [fol. 1350] voltage in the transmission line should be in phase."

and the patent further says:

"Such a result may be obtained if the transmission line is made reflectionless or of electrically infinite length. Under these conditions no waves can be reflected back from the ends to interfere with the natural flow of energy into and out of the transmission line."

The invention of the patent consists in making reflectionless the transmission line extending between the source of the current and the load. The patentee says in his specification

"This result may be obtained by closing the transmission line 10 at 11 in such a manner that the effective impedance at the load end of the line is equal to the surge impedance of the transmission line."

This statement means that the impedance of the load is matched to the impedance of the line throughout the entire length thereof.

The problem as stated is how to bring about or produce that condition.

The recital by Carter of what purports to be his solution of the problem amounts simply to this, the antenna resistance multiplied by the square of the feed ratio should be equal to the surge impedance of the line.

This is a statement in terms of results, without any instruction as to how to accomplish these results. The only thing shown in the drawings of the patent for accomplishing the result is a transformer, but there is no statement [fol. 1351] nor is it implied or indicated how the transformer is to be made, adjusted or set up in order to make it possible to close,

"the transmission line 10 at 11 in such a manner that the effective impedance at the load end of the line is equal to the surge impedance of the transmission line."

The first Carter patent in suit is a paper patent and in view of the prior art in evidence to wit: Alexanderson patent No. 1,360,167; Rice and Kellogg patent No. 1,602,085; Colpitts patent No. 1,129,959; Leblanc patent No. 874,411; Heising patent No. 1,313,483; Conrad patent No. 1,640,534; Reuthe patent No. 1,314,095 and Whiting patent No. 1,537,-101, it can be given only a limited range of equivalents sufficient to protect the invention of that patent.

Defendant does not employ any connection between a transmission line and a radiator, where at the point of connection, an impedance matching device is employed.

The defendant in every antenna under charge of infringement in this suit employs an impedance matching device located in the transmission line at a distance from the antenna wires.

No transformer connecting the end of the transmission line with the antenna is used by the defendant in any of its antenna systems under charge of infringement in this suit.

The defendant does not employ a transformer as an impedance matching device in any of its said antenna systems.

Claim 1 recites as the elements of its combination an [fol. 1352] energy radiating circuit (an antenna), a source of power for energizing said circuit (the generator), and a

transmission line of electrically infinite length connecting said circuit and said source.

Fig. 1 of the patent shows the transmission line 10 extending to the antenna, as is necessary in a system where a transformer connects the antenna with the transmission line, and the patent in suit instructs to terminate the line with a transformer.

No such arrangement or any arrangement which might be correctly described by this language is shown in any of the defendant's alleged infringing devices.

This is also true with respect to claims 2 and 5 in suit, the last element in each of which is defined as a reflectionless transmission line connecting the source and the antenna or radiating circuit.

Antenna No. 2, which is typical of its class, shows that the transmission line extends from the transmitter to the radiators (antenna wires ACBD) but the impedance matching device (KLMN) is located on the transmission line a substantial distance from the radiators, therefore defendant does not employ "a transmission line of electrically infinite length connecting the radiator (ACBD) and the source" (the transmitter).

Antenna No. 7 of defendant's devices has reflected waves on the entire portion of the transmission line leading from the power-house to where the transmission line branches, as well as from the radiators to the points E F and E′ F′.

By their terms each of claims 1, 2 and 5 are limited to a [fol. 1353] transmission line connecting the antenna and the source of power which is reflectionless throughout its length.

Defendant does not employ in any of its antenna systems a transmission line connecting the source of current to the radiating antenna, which is reflectionless throughout its length.

In defendant's devices the production of reflected waves on a portion of the defendant's line is a necessary expedient for successful operation and defendant's antenna system could not operate if defendant's arrangement were used in a manner to entirely eliminate reflected waves throughout the length of a transmission line. Defendant's antenna No. 2 (original) best illustrates this point.

Claim 7 of the patent in suit recites as the element of its combination

a plurality of antennae,
a single source for supplying energy to all of said antennae and,
transmission lines of electrically infinite length for supplying energy from said source to said antennae.

It thus appears that claim 7 is limited in addition to the limitations of claims 1, 2 and 5, to at least two transmission lines of electrically infinite length, which supply power from a single source to two or more antennas.

Plaintiff attempted, but unsuccessfully, to apply this claim to defendant's antenna systems like antenna No. 8.

From a careful consideration of the evidence, it appears that the defendant's devices, which are alleged to infringe, use a radically different arrangement to accomplish an old [fol. 1354] result, and irrespective of the validity of the patent in suit or whether or not the claims are readable on defendant's antennas. Westinghouse v. Boyden Power Brake Co., 170 U. S. 537.

The defendant does not infringe the First Carter Patent No. 1,623,996.

The Second Carter Patent No. 1,909,610

This patent like the first Carter patent, is directed to the subject matter of matching the surge impedance of the line to the impedance of the load to which the line feeds. As its object is identical with that of the first Carter patent, which was applied for nearly seven years and issued nearly three years prior to the application of the Second Carter patent, the subject matter of the said Second Carter patent is and must be confined to the particular instrumentalities, arranged in the particular way shown and described by the patent to effect impedance matching.

The Second Carter patent is not specifically directed or limited to use in connection with radio antennas, but to electric circuits in general and for use in any field where reflectionless transmission lines, matched impedances, elimination of standing waves, etc., are desired.

The patentee in his specification says:

"This invention relates to electric circuits and especially to a transmission line supplying high frequency currents to a high frequency load circuit"

and then recites what is well known in the prior art

[fol. 1355] "In order that the line transmit energy at best efficiency; that is to say, without reflection, it is desirable that the line be terminated by a load which equals in impedance the surge impedance of the line."

After noting that lines and loads are independently designed, and that existing lines must be connected with existing loads which do not have the requisite values of impedance for best energy transmission, the patentee states

"it is an object of my invention to provide a method and means for terminating a line to which a load is connected so that the termination means combined with the load presents the correct impedance to the line. More specifically, I accomplish this by connecting a variable reactance across the line at a distance away from the load such that the circuit formed thereby including the variable reactance, the line portion between it and the load, and the load, presents an impedance equivalent to the surge impedance of the line."

On its face the patent admits, in substance at least, that it differs from the disclosure of the first Carter patent only in the specific "method and means for terminating a line." The patentee then says:

"In a case wherein the surge impedance is greater than the load impedance or resistance, I have discovered that by connecting a capacitive reactance across the line at a dis-[fol. 1356] tance not more than one-quarter of a wave length of the energy transmitted by the line away from the load; or, by connecting an inductive reactance across the line at a distance more than one-quarter wave length but less than one-half wave length of the load, the combination of the reactance and the load and portion of the line included between the reactance and the load becomes equivalent, with proper quantitative values of the electrical elements involved to the surge impedance of the line, thereby facilitating efficient energy transmission."

and then says:

"Similarly I have discovered that when the surge impedance of the line is less than the load impedance, by connecting an inductive reactance across the line not more than one-quarter wave length away from it; or, a capacitive re-

actance across the line more than one-quarter wave length but less than one-half wave length away from the load, that the combination of reactance, load and portion of the line included between the reactance and the load becomes equivalent, with proper quantitative values of the electrical elements involved to the surge impedance of the line thereby properly terminating it for maximum energy transmission.''

From the foregoing quotations from the patent it appears that whether the surge impedance is less or greater than the load impedance, the patentee connects a variable reactance across the line, viz.: in shunt to the load. That where the surge impedance is greater than the load the reactance is [fol. 1357] either capacitive with its point of connection across the line ''not more than one-quarter wave length away from the load'', or it is inductive located ''more than a quarter wave length but less than one-half wave length away from the load''. That where the surge impedance is less than the load impedance the resistance connected across the line is either inductive and positioned ''not more than one-quarter wave length away from the load'', or is capacitive and is connected across the line ''more than one-quarter wave length away from the load.'' That the desired result is attained under either set of conditions only ''with proper quantitative values of electrical elements.''

The specification describes the arrangements shown in the drawings and sets forth in a table the discovery of the patentee recited in the two paragraphs of the patent hereinbefore quoted.

The disclosure of the patent in brief is that impedance matching may be effected by connecting a variable reactance of proper value across the line at a proper distance from the load. The patent recognizes and twice states that the object of the invention can be attained only ''if proper quantitative values of the electrical elements involved'' are used, but is silent as to how those values can be ascertained. Further the patent conveys the idea that at any point within a quarter wave length distance from the load (in the one case), or more than one-quarter wave length but not greater than one-half wave length (in the other case), a reactance connected across the line would obtain the desired result,

[fols. 1344-1345] IN UNITED STATES DISTRICT COURT, EASTERN DISTRICT OF NEW YORK

Equity. No. 7234

RADIO CORPORATION OF AMERICA, Plaintiff,

against

MACKAY RADIO AND TELEGRAPH COMPANY, INC., Defendant

October 14th, 1936.

Sheffield & Betts, Esqs., Solicitors for Plaintiff; Jo. Baily Brown, Esq., Harry Tunick, Esq., and Abel E. Blackmar, Jr., Esq., of Counsel.

Darby & Darby, Esqs., Solicitors for Defendant; Hugh M. Morris, Esq., Samuel E. Darby, Jr., Paul Kolisch, Esq., and Roy C. Hapgood, Esq., of Counsel.

OPINION

CAMPBELL, D. J.:

This is a suit for the alleged infringement of certain claims of five patents as follows:

1. Patent No. 1,623,996 issued to Philip S. Carter assignor to Radio Corporation of America for Radio Transmission System, granted April 12th, 1927, on an application filed June 25th, 1923, of which claims 1, 2, 5 and 7 are in suit. This patent will be hereinafter referred to as the first Carter patent.

2. Patent No. 1,909,610 issued to Philip Staats Carter assignor to Radio Corporation of America for Electric Cir-[fol. 1346] cuit, granted May 16th, 1933, on an application filed March 12th, 1930, of which claims 1 to 5 inclusive are in suit. This patent will be hereinafter referred to as the second Carter patent.

3. Patent No. 1,884,006 issued to Nils E. Lindenblad assignor to Radio Corporation of America for Antenna, granted October 25th, 1932, on an application filed September 7th, 1928, of which claims 23 to 27 inclusive are in suit. This patent will be hereinafter referred to as the first Lindenblad patent.

whereas in fact to attain the results of the patent the point of proper connection of the reactance across the line, that [fol. 1358] is its distance from the load, was precise and exact in each instance.

This constitutes the whole disclosure of the Second Carter patent in suit.

All five claims of the patent are in suit and each is for a combination.

Claim 1. The elements of the combination of claim 1 are (1) a source of energy, (2) a load, (3) a transmission line extending between the source of energy and the load and (4) means for matching the load to the surge impedance of the line consisting of

(a) a reactance connected across said line between said load and said source and so arranged that

(b) a portion of said line is located between said reactance and said load,

(c) said reactance having such value that the combination only of the load, portion of the line, and the reactance

(d) becomes equivalent to the surge impedance of said transmission line.

Claim 2 differs from claim 1 in defining the reactance as "a variable element", and in defining the transmission line as "an unbroken linear connection characterized by the absence of serially connected impedances between said source and said load".

Claim 3 is specific to the situation where the transmission line has a surge impedance greater than the load resistance; the shunt reactance being defined as "a capacitive reactance" connected across the line between the load and [fol. 1359] the source a distance from the load not exceeding a quarter wave length.

Claim 4 is likewise specific to the case where the transmission line has a surge impedance greater than the load resistance, but wherein the shunt resistance is inductive and is connected across the line between the load and the source at a distance greater than one-quarter wave length and less than one-half wave length from the load.

Claim 5 is specific to the case where the transmission line has a surge impedance less than the load resistance, and

there is employed for the shunt resistance an inductance connected across the line at a distance from the load less than a quarter wave length therefrom.

Claims 3 and 4 are specific in reciting that the transmission line has a surge impedance greater than the load resistance; and Claim 5 in stating that the transmission line has a surge impedance less than the load resistance.

Although plaintiff contends that defendant's antennas infringe all of the claims in suit it has not shown which of the two aforesaid conditions prevails in any of defendant's antennas.

In view of the first Carter patent in suit, Whiting patent 1,537,101, British patent to Franklin 282,905 and Lindenblad patent 1,884,006, the Second Carter patent in suit cannot have a wide range of equivalents but must be limited to the protection of the invention of the Second Carter patent in suit, which is confined to the particular instrumentalities, arranged in the particular way shown and described by the [fol. 1360] patent to effect impedance matching.

The main object of the Second Carter patent in suit is to provide a transmission line reflectionless throughout its length and none of defendant's transmission lines is reflectionless throughout its length.

This has been fully discussed in this opinion in my consideration of the charge of infringement of the First Carter patent in suit and need not be repeated.

To accomplish its object the Second Carter patent in suit discloses only the connection across the transmission line of a lumped capacitance or a lumped inductance, as specified in each of the claims of the patent in suit and which as additionally provided in Claim 2, must be variable.

There is no lumped reactance connected across the line in any of defendant's structures. What defendant uses in every instance, is a plain wire which has only distributed inductance and distributed capacitance. In no instance is the wire a variable element, as shown, described and claimed in the patent in suit. The only way the patent could be practiced at the time of its application was to experimentally ascertain the value of the reactance by the method of actually varying the value thereof, and therefore variability becomes a necessary limitation in each of the claims whether expressed therein or not.

The loops of the wire of the defendant's device are not variable in the sense in which a lumped condenser or induction coil is variable. It is true that by cutting off pieces of wire defendant's devices can be varied in one direction but [fol. 1361] the word variable as used in the patent does not mean "something which can be changed". Given that meaning, it would lose all sense as there is no element in a radio antenna system that is not variable in that sense. The term variable as used in the patent and shown in the drawings means the ability to increase and decrease the value of the inductance or capacity as the case may be. The defendant employs no variable element in the sense such term is employed either expressly or by inference in all of the claims of the patent in suit.

The plaintiff, on which rested the burden of proving infringement, has failed to bear that burden by offering any proof that in defendant's antenna systems there is a transmission line having a surge impedance greater than the load resistance as specified in claims 3 and 4 or a transmission line having a surge impedance less than the load resistance, as specified in claim 5.

The defendant used instrumentalities which are different in every respect from the instrumentalities which are disclosed in the patent in suit and if the distributed inductances and capacitances as used by defendant in its antennas charged to infringe are the equivalent of the lumped inductances and capacitances of the Second Carter patent in suit (which in my opinion they are not) then the patent would be anticipated by the British patent to Franklin No. 282,905.

Regardless of its validity, the Second Carter patent in suit is not infringed by any of the defendant's alleged infringing devices.

[fol. 1362] Having concluded consideration of the two patents in suit directed to the subject of impedance matching, I will now consider the three patents in suit directed to the subject of the antenna.

As expressly provided in the three antenna patents in suit, the main or principal lobes of radiation or, as it is sometimes termed, the "predominant radiation", must take place in the plane of the antenna wires, and as additionally provided in the second Lindenblad patent in suit and the third Carter patent in suit along the bisector of the V.

The main object of the three antenna patents in suit was to arrange two or more antenna wires so that radiation takes place in the plane of the wires horizontally if the wires are horizontal with respect to the ground and at an angle if the wires are tilted at an angle.

The wires are arranged parallel to one another in the first Lindenblad patent in suit and according to it the principal radiation is concentrated in the plane of the wires as distinguished from prior arrangements in which, according to Lindenblad, radiation took place in other directions outside of the plane.

The purpose of the second Lindenblad patent in suit was to improve on the first Lindenblad patent in suit by concentrating radiation not only in the plane of the wires, but along the axis of the V into which the two wires are formed, which constitutes the bisector of the angle formed by the wires.

The third Carter patent in suit has as its object to improve on the second Lindenblad patent in suit by achieving [fol. 1363] an even greater concentration in the plane of the wires along the bisector of the angle by selection of the proper angle between the legs of the V.

The defendant's antennas which are charged with infringement differ radically from the inventions claimed in the three antenna patents in suit. None of them propagate a main lobe of radiation in the plane of the wires, but intentionally propagate their main lobes of radiation at an angle to the plane of the wires for the deliberate purpose of utilizing the reflective effect of the Heaviside layer.

None of the defendant's antennas tilts the wires at an angle to the horizontal to accomplish this, but that alone, is contemplated by the patents in suit for that purpose. For the same reason, none of defendant's antennas propagates its main lobe of radiation on the axis of the system, or along the bisector of the angle between the legs of the V.

None of defendant's antennas (with the exception of antennas No. 8) uses radiator wires an integral number of half wave lengths long, as is specified by all three of the antenna patents in suit, but the defendant's radiator wires depart from the half wave length measure as far as it is possible so to do. This is done for the deliberate purpose of creating standing waves on a portion of the transmission line feeding

the antenna as is necessary in order to tune the antenna and effect impedance matching in defendant's system.

None of defendant's antennas utilize an angle between the legs of the V that is dependent upon the Carter formula as well as the Abraham formula, and this is especially true of defendant's aforesaid antenna No. 8, but also true as to the remainder of the antennas as Carter's formula is predi- [fol. 1364] cated upon the precise relation between the angle of propagation and the exact length of the antenna wires, which must be an integral number of half wave lengths in order to be accurate.

In substance all of the antenna patents in suit present merely a theoretical application of antenna wires in free space, whereas all of the defendant's are intentionally designed to co-operate with ground effect, which effect not only is not contemplated by any of the patents in suit, but is contradictory to the description and claims thereof.

The First Lindenblad Patent No. 1,884,006

This patent is directed to the use of staggered parallel wires as an antenna.

No evidence was offered which showed the adoption of this type of antenna by anyone, and defendant does not use parallel or staggered wires. To attain the stated objects of the patent by the use of parallel wire antennas, there must be proper spacing between the wires. This fact is expressly recognized by the patent which expressly misdirects with respect thereto. And the patent is expressly directed to obtain propagation of waves in the plane of the wires.

Figs. 1 and 2 of the drawings of the patent illustrate the well known single wire antenna which is characterized by the patent as "wasteful of energy".

The patentee in the specification says one object of his invention is

"to reduce the conical radiation so that it will consist only of concentrated lobes having axes in one plane. This is [fol. 1365] accomplished by providing two collaterally spaced substantially parallel linear conductors which are long, relative to the working wave length, and which are coupled in phase opposition."

This arrangement is shown in Fig. 3 and on comparison with Fig. 2 it will be seen that the conical radiation has been reduced by means of the parallel wire arrangement, to four

principal lobes of radiation 30, 34, 32 and 36, all in the same plane of the wires.

The patent also states:

"This arrangement, too, is wasteful of energy, and it is a further object of my invention to strengthen the radiation in one pair of opposite critical directions, while weakening the radiation in the conjugate pair of opposite critical directions, which I do by staggering the pair of wires, longitudinally, so that their ends make an angle with the transverse axis of the antenna equal to the critical angle of radiation, that is, the angle which the principal lobes of the radiation pattern of the antenna make with the longitudinal axis of the antenna."

Fig. 4 of the drawings shows this arrangement and on comparison with Fig. 3 it shows that two additional lobes in the same general direction have been joined, still in the plane of the wires. Only by staggering the ends of the parallel wires and spacing them from each other a proper distance can this effect be produced. A bidirectional antenna is secured in this way. To make the system unidirectional, [fol. 1366] as illustrated in Fig. 5 for example, a "reflector" is used, that is a duplication of the staggered parallel wires but, spaced therefrom a proper distance in the manner taught in the First Carter Patent, for example, which was admittedly old even at the date of Carter's first application 1923.

Every objective attained or sought to be attained thereby, is dependent upon the proper spacing between parallel wires.

In Fig. 4 is illustrated the subject matter of spacing between the parallel wires where it is shown that the wires are spaced from each other a distance determined by the formula recited, which distance is measured in the direction of radiation. This was an entirely erroneous teaching, and was not merely a draftsman's error or oversight as the mistake was carried into the text also where the erroneous is thrice supported in the specification.

Claims 23, 24, 25, 26 and 27 are in suit and claim 23, which may be taken as typical, reads as follows:

"23. A directional antenna comprising a pair of long linear wires connected at adjacent ends to high frequency apparatus and having standing waves of opposite instantaneous polarity thereon, said wires being several wave

lengths in length and extending away from and on one side only of said adjacent ends."

All of the claims in suit must necessarily be read in the light of the disclosure of the patent; that is they must be [fol. 1367] read as being directed to cover staggered, parallel wires employed as radiators from which radiation is effected in the plane of the wires. Unless the claims be so interpreted, they would fail to describe the invention of the patent as specified therein.

All of the claims in suit contain the limitation that the wires are "several wave lengths in length", and claims 25, 26 and 27 expressly recite that the wires are arranged so that radiant action occurs in a direction making the same angle with each conductor, which means that the wires are parallel to each other.

A consideration of the evidence leads me to the conclusion that regardless of the validity of the patent none of the defendant's antennas infringes the first Lindenblad patent in suit for the following reasons:

None of the defendant's antennas radiates waves in the plane of the wires, but in all of them the main lobe of radiation is at an angle to the plane of the wires.

None of the defendant's radiating wires or conductors is arranged parallel to each other but all of defendant's wires are in the form of a V.

None of defendant's antennas is longitudinally staggered with respect to one another in order to obtain bidirectional effect, but the open ends of the legs of defendant's V terminate opposite each other.

None of defendant's bidirectional antennas employ a pair of wires spaced from each other in accordance with the spacing formula, whether correctly applied or incorrectly applied as in the first Lindenblad patent in suit, but defendant's [fol. 1368] ant's single V antennas are bidirectional without using this feature.

None of defendant's antennas employ, in order to obtain unidirectivity, a reflector of parallel spaced staggered wires, but employs as its reflector another V antenna.

Defendant's antennas differ so radically in structure and principle of operation from those of the first Lindenblad patent in suit that if the claims in suit of that patent be even literally readable on defendant's antenna systems and so interpreted as to include within their scope defendant's an-

tennas or any of them, the claims would not define Lindenblad's invention. The claims do not literally read on defendant's antennas as there is of necessity imported into the claims, properly spaced parallel staggered wires, without which the directive system claimed in each of the claims in suit could not be obtained.

The first Lindenblad patent in suit is not infringed.

The Second Lindenblad Patent 1,927,522

This patent is for a traveling wave antenna. No evidence was offered of any adoption or use thereof by anyone. All of defendant's antennas charged to infringe are of the standing wave type. This patent likewise specifically directs and limits its disclosure to the propagation of the main lobe of radiation in the plane of the wires. Defendant does not employ any antenna in which the main lobe of radiation is in the plane of the wires. This patent is not directed broadly to a V-type antenna as it is wholly inadequate of disclosure because the proper angle between the antenna [fol. 1369] wires constituting the legs of the V is not given and no means are disclosed by the patent to enable one to determine the proper angle. Only with proper angles could the stated objects of the patent be attained, that is, that the main lobe of radiation would be in the plane of the wires and on the bisector of the angle between the legs of the V.

The patentee in his specification says:

"It is an object of my invention to provide an exceedingly simple form of short wave antenna, which will operate over a considerable range of frequency, and a further object of my invention is to provide an antenna with which a transmission line may be coupled without the use of intermediate impedance matching devices."

None of defendant's antennas is designed to "operate over a considerable range of frequency", but all of them employ "intermediate impedance matching devices". The patentee then states that the stated object is accomplished by the utilization of traveling waves. All of defendant's are of the standing wave type.

The second Lindenblad patent specifies that the principal radiation occurs in the plane of the wires and says:

"The desired radiation takes place in the direction of the axis of the pair of conductors."

Again reference is made to "radiation in the direction of the antenna".

[fol. 1370] No instruction is given in the specification as to the proper angle between the legs of the V, and such instruction is necessary because without the proper angle, maximum radiation in the direction of the bisector of the angle would not occur, as at certain values of the angle, zero radiation on the line of the bisector is obtained.

Claims 9, 10, 19 and 23 are in suit.

Claim 9 reads as follows:

"9. In combination, a two conductor transmission line excited in phase opposition, and an antenna extending longitudinally in the direction of desired radiant action comprising an open ended pair of conductors which at one end are spaced at the spacing of the transmission line and are coupled thereto, and which gradually diverge to a much wider spacing at their open ends."

Claim 10 also defines the antenna as

"extending longitudinally in the direction of desired radiant action".

These claims are therefore expressly limited to radiation in the plane of the wires.

Claim 19 expressly recites that radiant action

"occurs predominantly along the direction of the axis of the conductor system".

Therefore this claim is also expressly limited to the principal radiation being in the plane of the wires.

Claim 23 expresses the same thought but in different language where it expressly provides that radiant action

[fol. 1371] "occurs predominantly in a direction making equal angles greater than zero degrees".

with reference to the conductors.

As hereinbefore stated none of defendant's antennas are of the traveling wave type and therefore none of the defendant's antennas embody the alleged invention of the second

Lindenblad patent in suit irrespective of the terminology of the claims.

As hereinbefore pointed out the claims in suit show that they are by their terms expressly limited to radiation in the plane of the wires.

None of the defendant's antennas so operate.

Regardless of the validity of the patent the second Lindenblad patent is not infringed.

The Third Carter Patent No. 1,974,387

This patent is also directed to the V-type antenna, and the asserted contribution of the patent over the second Lindenblad patent consists of supplying the necessary formula for determining the proper angle between the antenna wires constituting the legs of the V in order to obtain maximum radiation in the plane of the wires along the line of the bisector of the angle between the legs of the V.

There is no evidence in this case that the defendant or anyone else has adopted or practically used the antenna of this type where radiation is effected in the plane of the wires on the line bisecting the angle between the legs of the V. Defendant deliberately and intentionally propagates its main lobe of radiation at an angle to the plane of the wires. [fol. 1372] The mathematical formula advanced as the invention of the patent was copied from the prior art formula of Abraham which had been used by engineers for determining the identical angle for which it was employed by Carter. This formula as employed by Abraham and Carter gives merely theoretical results, but was advanced by both of them as affording means for determining the angle between the principal lobe of radiation and the wire from which it radiates in free space, when the wire is an integral number of half wave lengths long. Defendant does not use antenna wires an integral number of half wave lengths long (with the exception of antenna No. 8), and antenna No. 8 together with all of the other antennas of defendant, charged herein to infringe, do not employ the angle prescribed by the formula. Defendant does not propagate its main lobe of radiation in the plane of the wires or on the bisector of the angle of the V. Due to the departure from the Carter patent in the respects enumerated and by reason thereof in all of defendant's antennas, here charged to infringe, defendant obtains material advantages and increased effi-

ciency in that material increase in radiated power is obtained.

That main radiation is desired and obtained by the patentee in the plane of the wires, and on the line bisecting the angle of the V formed thereby appears from the specification which says

"It is proposed to place these wires at an angle with respect to each other so that principal radiation takes place along the bisector of the angle" (p. 1, l. 22).

[fol. 1373] and again that the wires are disposed

"at an angle such that the principal radiation occurs along the direction of the bisector of the angle" (p. 1, l. 79).

There will also be found on page 2, lines 32, 34, 39, 44, 101, and on page 3, lines 40, 74, 84, 116 and 131 references of similar character.

The Abraham formula for determining the angle between the legs of the V is copied in the specification.

The application as originally filed was expressly limited in the specification and claims to antenna wires an integral number of half wave lengths long and the Abraham formula would correctly apply thereto.

During the prosecution of the case, and subsequent to the answer of the defendant filed in this suit, the specification was amended by the insertion of the following:

"By the term 'plurality of wave lengths,' or 'several half wave lengths', it is not intended that the wires so described shall necessarily be an exact or approximate integral number of such lengths, unless so specified, but rather that each of the wires so described shall be sufficiently long to include the lengths specified" (p. 4, ll. 35-42).

and the claims were amended correspondingly and in that form the patent issued. The object was to include an antenna of any length.

The claims in suit are claims 1, 2, 3, 4, 10, 12, 15, 16, 28, 34, 35, 36, 38 and 40.

[fol. 1374] Claims 1-4 are directed merely to the use of a V antenna with its reflector.

Claims 1-3 are expressly limited to the radiant action being

"predominantly along the direction of the bisector of the angle formed by the conductors."

and claims 1-4 were amended subsequent to defendant's answer in this case with reference to the length of the wires so as to "include" substantially a plurality of half wave lengths instead of being expressly limited to an integral number of half wave lengths as they were theretofore drawn.

Claims 10, 12, 15 and 16 all, at least, include as part of the invention of the Abraham formula in some form.

Claim 28 is directed to the reflector feature and contains the amendment as to the length of the wires of the V made after answer in this suit.

Claims 34, 35 and 36 are directed to the use of impedance matching devices with a V-type antenna. They are expressly limited to radiation on the bisector of the angle, and include the belated amendment as to the length of the wire.

Claim 38 differs from claim 1 only in more generally defining the spacing of the reflector, and contains the belated amendment as to the length of the antenna wires.

Claim 40 is directed to the reflector feature with a V antenna and is expressly limited to radiation along the bisector of the angle between the legs of the V.

[fol. 1375] Defendant does not radiate in the plane of the wires, whereas the Third Carter patent in suit is expressly limited as to some claims, and impliedly as to all thereof, to radiation in the plane of the wires and, in fact, on the line bisecting the angle between the legs of the V.

Defendant does not employ antenna wires an integral number of half wave lengths long (with the exception of antenna No. 8).

The defendant's antenna wires in Nos. 1, 5 and 7 are approximately 6¼ wave lengths long, in Nos. 2 (original), 3 (original), 4, 6, 8 and 11, they are approximately 7¾ wave lengths long and in No. 10 they are approximately 7¼ wave lengths long.

Plaintiff contends that the Third Carter patent is the final development of the structure disclosed in the two Lindenblad patents in suit and it is alleged that the details of defendant's antennas come nearer to the Third Carter patent than to any other patents in suit. Let us now compare defendant's practices with the teachings of the Third Carter patent in suit.

The teachings of the Third Carter patent in suit in so far as the length of the antenna wires is concerned are the same as those of the two Lindenblad patents in suit.

The description and claims of the Third Carter patent in suit as originally filed and as they stood until August 1934, that is, subsequent to the commencement of this action, dealt only with antenna wires a plurality of half wave lengths long. Claim 1, originally numbered 5, defined the length of the conductors as

[fol. 1376] "*substantially a plurality of half wave lengths long.*"

and was amended August 4th, 1934 to read:

"of a length including substantially a plurality of half wave lengths".

The original language covered only antenna wires a plurality of half wave lengths long, but by the broadening amendment of August, 1934, it included all antennas irrespective of their lengths as long as they were at least one wave length long.

In the same amendment the same change was made in claims 6, 7, 8, 9, 10, 25, 31, 32, 33, 34, 39, 40, 43, 44, 45, 46, 47, 48, 49 and 50. Claims in suit 1, 2, 3, 4, 28, 34, 35, 36 and 38 were so amended. And the specification was amended as hereinbefore quoted.

The specification as filed and as it stood at the time of the commencement of the present action did not contain any such language as appeared in the amendment and the claims as they then stood would have excluded defendant's antennas.

I do not agree with plaintiff's contention that the original specification warranted such extension of Carter's disclosure.

After the refusal of the amendment of July 16th, 1934, which included the amendment to the specification hereinbefore quoted and after an oral interview with the Examiner the specification and claims were amended as hereinbefore quoted by the amendment of August 4th, 1934.

The expansion of the application was improper. DeForest v. General Electric Company, 283 U. S. 664.

[fol. 1377] The disclosure and the claims were broadened not only contrary to their original terminology but to their spirit as well. Carter throughout the specification dealt with conductors measured in half wave lengths or full wave lengths and did not mention conductors a multiple of a

quarter wave length long or conductors of greater or less than half wave lengths. The two Abraham formulæ are applicable only to wires an exact number of half wave lengths long. It is true that in Fig. 12 of the patent Carter drew a smooth curve which apparently includes all lengths of wire between the half wave lengths but I am convinced that neither Carter's empirical formula nor Fig. 12 make a correct showing of what happens when the wires are other than exact multiples of half wave lengths.

Another statement of the specification which plaintiff contends indicates that Carter had in mind antenna lengths which were not integral multiples of half wave lengths refers to

"open-ended wires of any finite length" (p. 1, ll. 29-34),

and does not refer to wires an odd or an even number of half wave lengths long.

Even this passage was added in the amendment of May 2, 1934, and after the commencement of this action.

Before all of the amendments were offered complete and detailed information of defendant's antenna systems was obtained by the plaintiff through litigation previously instituted on the first four patents in suit and by those amendments the plaintiff attempted to mold the third Carter [fol. 1378] patent both as to disclosure and claims, to cover defendant's antenna systems.

This could not lawfully be done. Lopulco Systems, Inc., et al. v. Bonnot Co., et al., 24 Fed. (2d) 510.

As I have hereinbefore stated, defendant's V antennas radiate at an angle to their planes and to their bisectors, and this is contrary to Carter's teachings. The Third Carter patent in suit deals only with horizontal radiation from an antenna in the plane of the wires and the bisector of the angle. There is no illustration of ground or its effect in the patent in suit. This is true even though in Fig. 7 of the patent in suit the legend appears:

"Power Distribution
Vertical Plane
Ground Effect Neglected"

This casual reference to ground does not show that Carter recognized ground effect, as no mention is made thereof anywhere in the specification nor is there any explanation

therein of what was meant by the legend. In any event the casual reference to "ground" contained in Fig. 7 is with reference to power distribution in the vertical plane and with that this litigation is not concerned. Fig. 6 of the patent in suit makes no reference to ground effect, and that relates to power distribution in the horizontal plane and with that this litigation is specifically concerned. I am convinced that the ground effect is without significance with respect to the invention purported to be shown, described and claimed in the Third Carter patent in suit.

[fol. 1379] To distinguish his invention from the Second Lindenblad patent in suit Carter amended his claims, and added new claims.

The Lindenblad patent does not show the relation between the angle and exact length of the antenna as Carter teaches, and in the claims as amended he defines the precise relation between the angle and the length of the antenna. The defendant does not use the precise relation of the Carter patent, and, in view of the Lindenblad patent, Carter could not obtain claims to cover a range of angles. All of defendant's antennas differ from the angle specified by Carter, and while the difference is not great, it is as great as the difference between Bruce (of the prior art) and Carter. If defendant's antenna No. 8, where the angle is differed 10% from Carter, infringes, then Lindenblad anticipates.

Regardless of the validity of the patent, the Third Carter patent in suit is not infringed.

Neither time nor space warranted a detailed consideration in this opinion of each of the contentions of the plaintiff, but they have all received consideration and I have stated my conclusions.

There are, however, certain contentions of plaintiff which I will briefly consider.

Defendant did not copy the antennas and instrumentalities of the patents in suit as contended by plaintiff, as all of the patents in suit, with the exception of the First Carter patent, issued subsequent to the erection of the defendant's antennas charged to infringe, and as I have found with respect to the First Carter patent defendant does not infringe.

[fol. 1380] None of the patents in suit are pioneer patents, as contended by plaintiff, and the record does not show that they have been employed by anyone; even the plain-

tiff's own commercial structures do not follow the teachings or employ the instrumentalities shown, described or claimed in any of the patents in suit, as I have interpreted the same. Therefore the patents in suit are not entitled to a construction of any broader scope than is clearly required to be given. Dernell Potato Products Co. v. Snelling, 38 Fed. (2d) 788-789; Stewart-Warner Corporation v. Jiffy Lubricator Co., 81 Fed. (2d) 786, 793.

Plaintiff makes a point that defendant offered no proof that defendant's antennas were the result of independent investigation and development by defendant, but in view of defendant's contention as to the patents in suit such proof would not be expected; the fact is, however, that defendant's systems are radically different from the patents in suit, in structure, principle of operation and instrumentalities, and were designed and constructed to secure and did secure greater radiation, by reason of such difference, than could be obtained by the patents in suit.

Plaintiff contends with reference to the Third Carter Patent in suit that the invention was of an antenna not a formula, but, even though that be so, the invention was of an antenna, the proper angle between the antenna wires constituting the legs of the V of which was to be determined by the formula supplied.

None of the claims in suit of any of the patents in suit are infringed by any of the antennas or antenna systems [fol. 1381] of the defendant charged in this suit to infringe.

A decree may be entered in favor of the defendant against the plaintiff dismissing the bill of complaint herein with costs.

Settle decree on notice.

Submit proposed findings of fact and conclusions of law in accordance with this opinion, for the assistance of the Court, as provided by the Rule 70½ of the Equity Rules and Rule 11 of the Equity Rules of this Court.

Marcus B. Campbell, U. S. D. J.

In United States District Court, Eastern District of New York

[Title omitted]

Stipulation re Findings and Conclusions

It is Hereby Stipulated by and between counsel for the parties hereto that the opinion of the Court rendered in this cause on October 14, 1936, be accepted as the findings of fact and the conclusions of law in the cause and in com- [fol. 1382] pliance with the provisions of Equity Rule 70½ and Rule 11 of the Equity Rules of this Court.

Sheffield & Betts, Attorneys for Plaintiff. Darby & Darby, Attorneys for Defendant.

Dated, New York, N. Y., December 29, 1936.

In United States District Court, Eastern District of New York

Equity. #7234

Radio Corporation of America, Plaintiff,

vs.

Mackay Radio and Telegraph Company, Inc., Defendant

Final Decree

The above cause came on to be heard upon the pleadings and evidence herein, and upon briefs and arguments by counsel for the respective parties, and thereupon, upon consideration thereof, a stipulation having been filed that the findings of the Court as set forth in its opinion shall be accepted as in sufficient compliance with Rule 70½ of the Equity Rules and Rule 11 of the Equity Rules of this Court [fol. 1383] requiring findings of fact and conclusions of law to be filed in said cause, it is

Ordered, Adjudged and Decreed:

1. That the bill of complaint herein, as well as the supplemental bill, be dismissed for want of equity.

2. That defendant recover from plaintiff its costs in the sum of Three Thousand Dollars ($3,000), for which judgment shall be entered in favor of said defendant.

Dated, December 30, 1936.

Marcus B. Campbell, U. S. D. J.

Dated Brooklyn, N. Y., December 29, 1936.

Approved as to form—

Sheffield & Betts, Attorneys for Plaintiff. Darby & Darby, Attorneys for Defendant.

[fol. 1384] In United States District Court, Eastern District of New York

[Title omitted]

Petition for Appeal

The plaintiff, Radio Corporation of America, feeling itself aggrieved by the Final Decree made and entered in the above entitled cause on the 30th day of December, 1936, does hereby appeal to the United States Circuit Court of Appeals for the Second Circuit from the said Decree, for the reasons set forth in the Assignment of Errors filed herewith, and it prays its appeal be allowed and citation issued as provided by law, and that a transcript of the record, proceedings and papers upon which said Decree was made, duly authenticated, be sent to the said United States Circuit Court of Appeals for the Second Circuit.

Dated, New York, N. Y., March 26th, 1937.

Sheffield & Betts, Solicitors for Plaintiff, Office and P. O. Address, 80 Maiden Lane, New York, N. Y.

[fol. 1385] Order Allowing Appeal

The foregoing Petition for Appeal is hereby allowed, and the plaintiff's bond or undertaking for costs on appeal is fixed at the sum of Two Hundred and Fifty Dollars ($250.00).

Dated, Brooklyn, N. Y., March 27th, 1937.

Marcus B. Campbell, U. S. D. J.

In United States District Court, Eastern District of New York

[Title omitted]

Assignment of Errors

Now Comes Radio Corporation of America, the plaintiff, by Sheffield & Betts, its solicitors, and, in connection with its petition for appeal, says that in the record of proceedings and in the Final Decree made and entered in the above cause on the 30th day of December, 1936, the Court erred:

1. In dismissing the Bill of Complaint herein.

2. In dismissing the Supplemental Bill of Complaint herein.

[fol. 1386] 3. In not granting the prayers of the Bill as to the Lindenblad Letters Patent No. 1,927,522, in suit.

4. In not granting the prayers of the Supplemental Bill as to the Carter Letters Patent No. 1,974,387, in suit.

5. In holding that claims 9, 10, 19, and 23 of the said Lindenblad Letters Patent have not been infringed by defendant's V antenna systems.

6. In not holding that claims 9, 10, 19, and 23 of the said Lindenblad Letters Patent have been infringed by defendant's V antenna systems.

7. In holding that claims, 1, 2, 3, 4, 10, 12, 15, 16, 28, 34, 35, 36, 38, and 40 of the said Carter Letters Patent have not been infringed by defendant's V antenna systems.

8. In not holding that claims 1, 2, 3, 4, 10, 12, 15, 16, 28, 34, 35, 36, 38, and 40 of the said Carter Letters Patent have been infringed by defendant's V antenna systems.

9. In holding that the said two Letters Patent in suit are restricted to the use of radiator wires an integral number of half wave lengths long.

10. In holding that in substance the said two Letters Patent present merely theoretical applications of antenna wires in free space, and in holding that ground effect not only is not contemplated by either of said Letters Patent, but is contradictory to the description and claims thereof.

[fol. 1387] 11. In holding that the said Lindenblad Letters Patent is restricted to a traveling wave antenna.

12. In holding that a mathematical formula was advanced as the invention of the said Carter Letters Patent, and in holding that said mathematical formula had been used by engineers for determining the identical angle between radiating wires of a directional antenna for which it was employed by Carter.

13. In holding that plaintiff, by amendment to the application for said Carter Letters Patent, improperly molded the said Letters Patent, either as to the disclosure or claims, to cover defendant's V antenna systems.

14. In holding that defendant's V antenna systems are radically different from those of said Letters Patent, in structure, principle of operation, and instrumentalities, and that they were designed and constructed to secure, and did secure, greater radiation by reason of such difference, than could be obtained by the structures of said Letters Patent, and in not holding that the V antennas described in the said Carter Letters Patent and the V antennas used by defendant, inevitably operate and function in the same way.

15. In holding that defendant deliberately and intentionally propagates its main lobe of radiation at an angle to the plane of the wires, and in holding that there is any departure by defendant from the teachings of the said Letters Patent in that respect.

[fol. 1388] 16. In holding that defendant's V antennas do not employ the angle taught by the said Carter Letters Patent.

17. In holding that there is no evidence in this case that the defendant, or anyone else, has adopted, or practically used, the antennas described in said two Letters Patent.

18. In not holding that the said Lindenblad Letters Patent described the first directive antenna in the art formed by a pair of long straight wires arranged in a common plane at an acute angle to each other and fed in phase opposition at their adjacent ends.

19. In not holding that the said Carter Letters Patent constituted the first disclosure in the art of directional radio communication of an antenna comprising a pair of simple

long straight wires arranged in horizontal V-formation, the wires being fed in phase opposition at their adjacent ends, the wires being of the length and arranged at the angle effective to produce maximum radiation in the direction of the bisector of the angle of said wires.

Wherefore plaintiff prays that the aforesaid Final Decree of the United States District Court for the Eastern District of New York may be reversed to the extent that plaintiff is appealing therefrom.

Dated, New York, N. Y., March 26th, 1937.

Sheffield & Betts, Solicitors for Plaintiff.

[fols. 1389-1390] Bond on appeal for $250.00 omitted in printing.

[fol. 1391] Citation, in usual form, omitted in printing.

[fol. 1392] In United States District Court

Statement re Stipulations and Orders Extending Time

Stipulations and orders were entered and filed extending the time for filing the transcript of record in this suit in the United States Circuit Court of Appeals for the Second Circuit and the time for securing the approval and filing the statement of evidence and praecipe to be included in said transcript of record to June 25, 1937, to August 25, 1937, to September 25, 1937, and to October 25, 1937, respectively.

[fol. 1393] In United States District Court, Eastern District of New York

[Title omitted]

Stipulation and Order Extending Time

It is Hereby Stipulated by and between the solicitors for the respective parties that the time for filing the transcript of record in the above entitled suit in the United States Cir-

cuit Court of Appeals for the Second Circuit on appeal by plaintiff, be extended to November 26, 1937.

Dated, New York, N. Y., October 18, 1937.

Sheffield & Betts, Solicitors for Plaintiff. Darby & Darby, Solicitors for Defendant.

It is so ordered this 19th day of October, 1937.

Percy G. B. Gilkes, Clerk.

[fol. 1394] IN UNITED STATES DISTRICT COURT, EASTERN DISTRICT OF NEW YORK

[Title omitted]

STIPULATED PRAECIPE FOR TRANSCRIPT OF RECORD

To the Clerk of the United States District Court for the Eastern District of New York:

It is Hereby Stipulated and Agreed by and between the parties hereto, through their respective solicitors, subject to the approval of the Court, that the printed transcript of record on appeal should conform to the following terms of this praecipe and contain the following:

1. Bill of Complaint.
2. Defendant's answer.
3. Motion for Leave to File Supplemental Bill of Complaint, Order thereon, and Supplemental Bill of Complaint.
4. Defendant's Answer to Supplemental Bill of Complaint.
5. The narrative and condensed statement of evidence of the witnesses at the trial as stipulated and agreed on by the [fol. 1395] solicitors for the parties and as approved by the Court on the 8th day of October, 1937.
6. Stipulation and Order approving the narrative statement of evidence.
7. The following exhibits:

Documentary:

Plaintiff's—1, 2, 3, 4, 5, 7, 8, 9, 10, 11, 12, 13, 14, 15 (only the side and end elevations [second row of diagram] and the plan view [third row] of the antenna, together with the printed matter at the bottom), 16, 17, 18, 19 (sections H, L,

and title only), 20, 21, 22 (cover, pages 2, 4 to 6 inclusive, and 20 to 27 inclusive), 23a, 24, 27, 28, 30, 31, 32, 36, 37, 38, 39, 40, 41, 42, 43 (and stipulation of April 21, 1936), 44, 45, 46, 47, 48, 51, 52, 53, 54, 57 and 58.

In lieu of Plaintiff's Exhibit 55, a statement reading as follows:

"Plaintiff's Exhibit 55 is a certified copy of an application for Letters Patent of the United States for 'Improvement in Horizontal Vee-Type Antenna', filed by or on behalf of Edmond Bruce on February 3, 1931, bearing Serial No. 513,063. The British patent No. 392,201, issued to assignees of Edmond Bruce (constituting Plaintiff's Exhibit 41 and reproduced above), was issued upon an application filed in Great Britain under the Convention and corresponding to the above-mentioned U. S. application Ser. No. 513,063 (Plaintiff's Exhibit 55)."

[fol. 1396] Defendant's—A, F, G, S, T, U, V (translations only of Abraham 1898 and 1901 articles, Bergmann article and the Bontsch-Bruewitsch article), W, X, Y, Z, AA (as to Bethenod French patents Nos. 596,737 and 625,293, the Levy French patent No. 593,570 and the patent of addition No. 30,798, and the Takagishi Japanese patent, include only the translations and drawings), BB, CC, DD, FF, GG, HH, JJ, KK, LL, MM, NN, OO (title page and pages 675 and 681 only), PP, QQ, UU, and VV.

Physical:

Plaintiff's—29.

8. Opinion of Marcus B. Campbell, District Judge.
9. Stipulation of December 29, 1936, with respect to findings of fact and conclusions of law.
10. Final Decree dated December 30, 1936.
11. Petition for appeal and Order allowing appeal.
12. Plaintiff's assignment of errors.
13. Undertaking for costs filed by plaintiff (omitting justification of Surety Company and affidavit).
14. Citation.
15. Stipulations and Orders extending time to file transcript of record, obtaining approval and filing of state- [fol. 1397] ment of evidence and praecipe (or statement covering such Stipulations and Orders).

16. This Praecipe and Order approving same.
17. Stipulation as to printed record and Order thereon.
18. Clerk's certificate.

Sheffield & Betts, Solicitors for Plaintiff. Darby & Darby, Solicitors for Defendant.

Dated, New York, N. Y., October 9, 1937.

It is so ordered this 11th day of October, 1937.

Marcus B. Campbell, U. S. D. J.

[fol. 1397a] In United States District Court, Eastern District of New York

[Title omitted]

Stipulation and Order Extending Time

It is Hereby Stipulated by and between the solicitors for the respective parties that the time for filing the transcript of record in the above entitled suit in the United States Circuit Court of Appeals for the Second Circuit on appeal by plaintiff, be extended to December 27, 1937.

Dated, New York, N. Y., November 18, 1937.

Sheffield & Betts, Solicitors for Plaintiff. Darby & Darby, Solicitors for Defendant.

It is so ordered this 19th day of November, 1937.

Percy G. B. Gilkes, Clerk.

[fol. 1397b] In United States District Court, Eastern District of New York

[Title omitted]

Stipulation and Order Extending Time

It is Hereby Stipulated by and between the solicitors for the respective parties that the time for filing the transcript of record in the above entitled suit in the United States Cir-

cuit Court of Appeals for the Second Circuit on appeal by plaintiff, be extended to February 4, 1938.

Dated, New York, N. Y., December 15, 1937.

Sheffield & Betts, Solicitors for Plaintiff. Darby & Darby, Solicitors for Defendant.

It is so ordered this 20th day of December, 1937.

Percy G. B. Gilkes, Clerk.

[fol. 1398] IN UNITED STATES DISTRICT COURT, EASTERN DISTRICT OF NEW YORK

[Title omitted]

STIPULATION AND ORDER AS TO RECORD

It is Hereby Stipulated and Agreed, that the foregoing (in 2 Vols.) is a true copy of the transcript of the record of the said District Court in the above entitled matter as agreed on by the parties.

Dated, Feb. 1st, 1938.

Sheffield & Betts, Solicitors for Plaintiff. Darby & Darby, Solicitors for Defendant.

On reading the foregoing consent of the solicitors for the respective parties herein, it is

Ordered that the foregoing printed record be filed in lieu of the original papers for the purpose of certifying a record on appeal.

Dated, Feb. 2nd, 1938.

Marcus B. Campbell, U. S. D. J.

[fol. 1399] Clerk's certificate to foregoing transcript omitted in printing.

[fol. 1400] UNITED STATES CIRCUIT COURT OF APPEALS FOR THE SECOND CIRCUIT

RADIO CORPORATION OF AMERICA, Plaintiff-Appellant

against

MACKAY RADIO AND TELEGRAPH COMPANY, INC., Defendant-Appellee

Before Manton, L. Hand and Swan, Circuit Judges

Appeal from the District Court for the Eastern District of New York. Suit for infringement of patents. Decree for defendant; plaintiff appeals. Decree modified.

Sheffeld & Betts, Jo. Baily Brown, Abel E. Blackmar, Jr., Harry Tunick, of Counsel for Appellant.

Darby & Darby, Attorneys for Appellee. Hugh M. Morris, Samuel E. Darby, Jr., Paul Kolisch, Roy C. Hopgood, E. D. Phinney, of Counsel.

MANTON, Circuit Judge:

This appeal involves the validity and infringement of the Lindenblad patent No. 1,927,522, granted September 19, 1933, on an application filed December 24, 1928, and the Carter patent No. 1,974,387, granted September 18, 1934, on an application filed June 11, 1930. Both are for short wave directional antennas composed of a pair or pairs of long wires, the two wires of each pair being placed at an [fol. 1401] angle to each other to form a V. Claims 9, 10, 19 and 23 of the Lindenblad patent and Claims 15 and 16 of the Carter patent are in issue.

Directive radio transmission is of commercial importance where communication is regularly carried on between two or more fixed stations. The advantage of highly directive systems for point to point communication is that interference with other systems is reduced and for a given amount of energy sent out by the transmitting station, a stronger or more reliable signal is heard at the desired receiving point. When radio waves are directed or concentrated upon a given receiver, freedom from interference follows. If the transmitter in New York concentrates its radio waves upon a receiver in a city in Central Europe, no waves or only feeble waves will travel in other directions and as a result other

receiving stations to the north, west or south points will not be subjected to interference. If the New York station transmits using a highly directive antenna (as Carter) which concentrates most of the 360 kilowatts of power into a bundle of rays confined within an angle of 20° or less, there would be substantially the same total power concentrated within 1/18th of the full compass circle or nearly 18 kilowatts compressed into each one degree sector instead of only one kilowatt. Thus, much of the power that would be wasted if the waves were broadcast in all directions may be brought to bear upon a particular receiving station and the intensity of the receiving signal multiplied.

The best antenna to serve these purposes appeared in 1926 as the Marconi beam antenna. It was made up of a complex network composed a large number of short wires. It [fol. 1402] was highly directive and expensive costing about $100,000. to produce. It was difficult to adjust and keep in repair.

Appellant's models B and C were built in 1929. They were built of pairs of long parallel, simple wires which co-operated to give highly directional effects. They were built at a cost of $30,000 and $48,000 and were made under prior Lindenblad patents.

No successful use of any other directional wireless is referred to until antennas made under the patents here to be considered were built. The first step in the directive antenna (made as Model D) under these patents was developed in the invention of Lindenblad. The primary units (like Models B and C) were made of long simple wires and the antenna consisted of two such wires placed at an angle with each other to form a V. Although the V-antenna described by Lindenblad had utility, it was not adapted for commercial use until Carter's improvement had been applied for. This antenna consists of one or more pair of long, straight, unmodified wires placed at a preferred angle; when a simple V is used the antenna is bi-directional. The predominant radiation of radio waves from the antenna is in two directions, the direction determined by the line bisecting the angle between the wires. By the use of two V's properly spaced with respect to each other and fed with current in proper phase relation, unidirectional action is secured. The predominant radiation is in one direction only. The direction of the bisector of the angle between the wires is either forward or backward according to the

connection used. This is the Carter patent. It was an im-[fol. 1403] provement over the directive antennas which had preceded it. Its cost was $5,000 as against $30,000 for the cheapest previous types. Its directivity was equal to the Marconi beam.

Although the theory of operation of a single wire had been previously developed prior to Lindenblad and Carter, no one had found how the theory could be utilized in the solution of the problem of constructing a highly directive antenna. One of the steps in the development of Carter's patented antenna is set forth in the Lindenblad patent. A long wire V antenna is shown in fig. 2. In the antennas of each of the patents energy is fed into the antenna by transmission line through an impedance matching device, in such manner that the energy fed to one antenna wire is of opposite phase to that fed to the other wire, that is, when the potential at any point on one wire is positive, that of the corresponding point on the other is negative and vice versa.

Lindenblad says that the current on the antenna wires may be in the form of standing waves, or "as a refinement" and "a further object of my invention" is in the form of travelling waves. He says that with travelling waves the sideways radiation is less than with standing waves, but the reduction of radiation in undesired directions may be obtained by other means.

Lindenblad stated nothing as to the advantages of any specific angle between the wires of his V-antenna and as to any relation between preferred angle, wire length and wave length. He said that the spacing between the ends of the wires "while variable" over a long range should be in the neighborhood of a fifth of the length which, regardless of [fol. 1404] wave lengths and wire lengths, means an angle under 12° between the wires. The wire length suggested is of the order of five or ten waves long. Carter taught 12° is not the most desirable angle for a V-antenna having wires of these lengths. He developed the theory of long wire V-antennas and taught how to construct them so as to secure maximum directivity by co-ordinating the angle wire length and wave length. He found that the use of a preferred angle for any given wire length and wave length gave an antenna which was equal or superior in directivity to any known antenna and far less costly to erect. Carter described multiple V-antennas both for preventing undesired high angle

radiation, for securing further concentration in the horizontal or compass direction and for securing unidirectivity.

Claim 10 of the Lindenblad patent is typical and will be selected in determining the question of infringement. It reads:

"In combination, a transmission line, and an antenna extending longitudinally in the direction of desired radiant action connected thereto comprising a pair of open ended conductors of the order of magnitude of a number of wave lengths long which are widely spaced at the ends remote from the transmission line and energized with energy of opposite polarity, and spaced at the spacing of the transmission line at their junction therewith."

The inventor intended to get rid of standing waves and he was to accomplish it by lengthening his antenna which eliminated reflection in the antenna. It, however, made the space between the conductors too long to be practicable. His figs. 3 and 4 show the conductors bend back and forth [fol. 1405] across each other and these figures were for travelling waves only. Fig. 2 was a standing wave antenna and would need an impedance matching device unless the transmission line was very short. He expected some standing waves and thought to improve on the di-pole.

Carter's Claim 15 reads:

"An antenna comprising a pair of relatively long conductors disposed with respect to each other at an angle substantially equal to twive 50.9 $\left(\frac{1}{\lambda}\right)$—0.513 degrees, 1 being the length of the wire and λ the operating wave length in like units, and means in circuit with said antenna for exciting the conductors in phase opposition whereby standing waves of opposite instantaneous polarity are formed on the conductors throughout their length."

Claim 16 differs from Claim 15 primarily in calling for "a similar parallel pair of conductors spaced at odd number of quarter wave lengths away from said first mentioned pair along the bisector of the angle of the conductors."

The appellee's V-antenna wires are relatively long. The angles used by it are all substantially the angles determined by the formula set forth in Carter's Claim 15.

Appellee constructs its V-antenas (Nos. 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11) utilizing in most instances substantially the exact angle specified by Carter, and places them upon poles 80 feet high and secured antennas that were effective in the identical directions that Carter described. Structurally the antennas are Carter's and secure the same results as he describes, that is, concentration of radiation on the distant receiving antenna, simplicity and efficiency. They are used to obtain the results Carter sought. The angle between each [fol. 1406] wire of appellee's antenna No. 2 and the bisector of the angle between them is 17.5°. Carter's formula and curve call for an angle of approximately 17.8° for wires of this length. The compass bearing of the bisector of this antenna is N. 49.75° E. This is referred to as the directivity of the antenna. This particular antenna is shown to have been used for communication between Vienna and Sayville, L. I., the direction of which is N. 49.74° E. from Sayville, which is substantially that of the bisector.

No. 1 is representative of appellee's double V antennas and it too is established to infringe. Indeed, the difference in each is trifling except No. 8 where there is a divergence of about 10%. 22½° as against 25°. No 10 has a departure of 5% away from the prescribed angle. These we think are substantially the same as the empirical angle. By appropriating Carter's idea, the substance of his discovery was taken and there is infringement.

Lindenblad in his V-shaped antenna greatly reenforced transmission. His angle was a little less than 12° and was practicable. Claim 10 required widely spaced conductors but the appellee used an angle never less than 17.5 and cannot be charged with infringement if the claim be limited as it should. It cannot be read more broadly for it appears that on several angles such an antenna will not operate. The problem was how to proportion the conductor length to the angle and this had to be worked out by trial. The patent gave no direction to the art, but it did give a suggestion. That is insufficient to cover the operations of the appellee and it may not be held to have infringed the Lindenblad patent.

[fol. 1407] It is argued that the patent is limited to antennas utilizing the predominant radiation which goes out exactly in the plane of the wires to the exclusion of that which goes at some small angle to that plane. When the

antenna is placed over ground on 80 foot poles, the presence of the ground affects radiation in certain ways but not so far as the directivity in compass direction is concerned. The unavoidable effects in the presence of ground are that radiation that has left the antenna in the exact mathematical plane parallel to the earth is, at a distance from the antenna, cancelled by a radiation that left the antenna at a slight downward angle and been reflected upward from the ground. Radiation which has left in a small upward angle, is reenforced by radiation that left at a similar downward angle and has been reflected from the earth's surface. These effects always occur when short wave antennas are placed as both appellant and appellee place theirs, that is, not far above the surface of the ground.

Cancellation of horizontal radiation does not destroy the effectiveness of the antenna as a source of signals for a distant receiving station. Long distance short wave transmission is not carried on by means of signals transmittted horizontally along the surface of the earth; the signals that reach a distant receiving antenna are those which have left the transmitting antenna at a small upward angle and been deflected back to earth by a portion of the upper atmosphere that reflects radio waves due to the fact that it is conductive [fol. 1408] because of ionization. The main consideration is that Carter described a practical directive antenna which is of great commercial utility when used just as he said it was to be used. He was concerned with antennas which would concentrate the radiation in certain compass directions. These antenna structures are used by both appellant and appellee.

It is next argued that the patent is limited to antennas, the wires of which are an integral number of half waves long. Most of appellee's antennas do not use wires that are of integral number of half wave lengths but that does not avoid infringement. Carter's application stated that the invention was applicable to wires of any finite length. His original application included the empirical formula and the curve of that formula is shown and described. Appellee's argument is based upon the limited application of the prior art Abraham formulas. The effect of this argument is to show that as to wires which are not an integral number of half waves long, the recognition that there was for such wires an angle of predominant radiation was not

obvious but was covered by Carter. Carter found that interpolation between these lengths was sufficiently accurate for practical purposes and disclosed the angles to use for V-antennas using wires of intermediate lengths. Appellee followed this disclosure and accomplished the results set forth by Carter.

Another argument advanced is that the patent is limited to antennas using the exact angle recommended by Carter. The argument proceeds that appellee's V-antennas utilize a slightly smaller angle than that recommended by Carter, with the result that the upwardly tilted radiation is still [fol.1409] more augmented by ground effect. But nine out of appellee's eleven V-antennas were found to be substantially the exact angle recommended by Carter and the other two were appreciably smaller.

We do not find that the prior art anticipated Carter's invention. The Bethenod French patent No. 596.737 was an old type of long wave antenna—two horizontal networks of wires one placed above the other, the two being fed in phase opposition. It fails to disclose the Carter invention for the latter was not merely for the use of long wires in antenna system but involved placing the wires in the form of a V and at the preferred angle disclosed. Bethenod failed to disclose either of these arrangements. His parallel net works taught nothing to the art in the solution of the problem here involved. It is insufficient to invalidate this patent disclosing a meritorious invention. Babcock & Wilcox Co. v. Springfield Co., 16 Fed. 2, 964 (C. C. A. 2); Electro-Bleaching Gas. Co. v. Paradon Engineering Co., 12 Fed. 2, 511 (C. C. A. 2).

The Bethenod French Patent No. 625,293 discloses a single wire antenna. The novelty of this arrangement is in the feed system but not in the antenna. Even though it disclosed an electrically long wire it does not disclose the two wire V-antennas of the Carter patent. He shows a single wire which he says may be placed at an angle with respect to the ground and appellee argues that this single wire with its image in the ground constitutes a pair of wires. This is referred to as the image theory. But the testimony of the experts clearly refutes this theory. The image in the ground of an actual wire above the ground is [fol. 1410] purely a theoretical consideration. After an antenna has been designed, the image theory may be used to analyze the ideal effect of ground upon its radiation.

But it is quite different from taking a prior antenna and its image and attempting to use those as a new antenna. The record discloses no one has ever attempted to do that. Moreover, the actual wire and its image is never equivalent to a two-wire antenna for a two-wire antenna necessarily is more than twice as directive as a single wire antenna including its image.

The French patent to Levy No. 593,570 (and the addition thereto of No. 30,798) shows two networks each composed of three electrically short wires, the network being fed in phase opposition. Levy's wires were short and he failed to appreciate any advantage in the use of long wires which constitute the fundamental antenna unit of Carter. He, like Bethenod, is indefinite as to the obtaining of a directive action with his antenna. He does not tell what type of directivity may be secured or how any desired kind of directivity may be secured. He uses parallel wires in each of his networks and failed to make any provision with respect to feeding the individual wires in such a way that each network as a whole will radiate substantially as though it were a single wire. The radiation of such networks is uncertain because the phasing and relative position of the wires are not definite.

The alleged prior invention of Bruce does not anticipate. He had experience in the study of short wave antenna problems and did seem in 1926 to have thoughts of a directive antenna composed of a pair of simple straight long wires [fol. 1411] arranged in common plane, but he failed to appreciate the possibilities of a long wire V-antenna nor did he recognize the possibilities of such construction. It was after the patents in suit had become known that he proceeded to obtain his result. His experiments previous to the work of Lindenblad and Carter were no more than abandoned efforts. Such abandoned experiments even though they utilized the exact patented structure, which Bruce did not, have been held insufficient to invalidate a patent. Coffin v. Ogden, 18 Wall. 120; Deering v. Winona Harvester Wks., 155 U. S. 286; The Corn-Planter Patent, 23 Wall. 181.

The Abraham articles of 1898 and 1901 with the formula suggested, although 30 years old, had never been utilized. From that time was the entire period of the development of the radio art. While his formulas unquestionably had useful scientific interest to radio engineers, they failed to

teach how to construct a directive antenna. Nothing in them suggests the inventions of Carter.

The problem solved here was of long standing and it was an eminently successful solution. Critical examination of prior patents and uses finds nothing invalidating the Carter invention and it shows a substantial accomplishment.

The decree will be modified holding the Lindenblad patent not infringed and the Carter patent valid and infringed.

Decree modified accordingly.

[fol. 1412] United States Circuit Court of Appeals, Second Circuit

At a stated term of the United States Circuit Court of Appeals, in and for the Second Circuit, held at the United States Court House, in the City of New York, on the 9th day of May, one thousand nine hundred and thirty-eight.

Present: Hon. Martin T. Manton, Hon. Learned Hand, Hon. Thomas W. Swan, Circuit Judges.

Radio Corporation of America, Plaintiff-Appellant,

vs.

Mackay Radio and Telegraph Company, Inc., Defendant-Appellee.

Appeal from the District Court of the United States for the Eastern District of New York.

This cause came on to be heard on the transcript of record from the District Court of the United States for the Eastern District of New York, and was argued by counsel.

On Consideration Whereof, it is now hereby ordered, adjudged, and decreed that the decree of said District Court be and it hereby is modified in accordance with the opinion of this Court.

It is further ordered that a mandate issue to the said District Court in accordance with this decree.

Wm. Parkin, Clerk.

[fol. 1413] Endorsed: United States Circuit Court of Appeals, Second Circuit. Radio Corporation of America vs. Mackay Radio and Telegraph Company, Inc. Order for

Mandate. United States Circuit Court of Appeals, Second Circuit. Filed May 9, 1938. William Parkin, Clerk.

[fol. 1414] UNITED STATES OF AMERICA,
Southern District of New York:

I, William Parkin, Clerk of the United States Circuit Court of Appeals for the Second Circuit, do hereby certify that the foregoing pages, numbered from 1 to 1413, inclusive, in 2 volumes, contain a true and complete transcript of the record and proceedings had in said Court, in the case of Radio Corporation of America, Plaintiff-Appellant, against Mackay Radio and Telegraph Company, Inc, Defendant-Appellee, as the same remain of record and on file in my office.

In Testimony Whereof, I have caused the seal of the said Court to be hereunto affixed, at the City of New York, in the Southern District of New York, in the Second Circuit, this twenty-first day of May, in the year of our Lord one thousand nine hundred and thirty-eight, and of the Independence of the said United States the one hundred and sixty-second.

Wm. Parkin, Clerk. (Seal United States Circuit Court of Appeals, Second Circuit.)

[fol.1415] SUPREME COURT OF THE UNITED STATES

ORDER ALLOWING CERTIORARI—Filed October 10, 1938

The petition herein for a writ of certiorari to the United States Circuit Court of Appeals for the Second Circuit is granted. And it is further ordered that the duly certified copy of the transcript of the proceedings below which accompanied the petition shall be treated as though filed in response to such writ.

Endorsed on cover: Enter Samuel E. Darby, Jr. File No. 42,612. U. S. Circuit Court of Appeals, Second Circuit. Term No. 127. Mackay Radio and Telegraph Company, Inc., petitioner, vs. Radio Corporation of America. Petition for a writ of certiorari and exhibit thereto. Filed June 17, 1938. Term No. 127, O. T., 1938.